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THE NORDIC REGION
– leading in green growth

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Nordic Council of Ministers
Ved Stranden 18
DK-1061 Copenhagen K
Phone (+45) 3396 0200

www.norden.org

Contents

Summary

In 2014 the Nordic Council of Ministers initiated a new bioeconomy project: "Test centers for green energy solutions – Biorefineries and Business needs". The purpose was to strengthen green growth in the area of the bioeconomy by analyzing and mapping the current status of the bioeconomy in the Nordic countries and identify potentials and obstacles, needs and opportunities. Based on this a set of policy recommendations was formulated.

The project group participants were prominent scientists within the field of bioeconomy as well as government officials from all the Nordic countries. The project was headed by Professor Lene Lange, DTU, Denmark.

The resulting Nordic Bioeconomy NCM Report consists of three parts:

1. Executive summary chapters (Introduction, Background, Scoping, Conclusions, Trends, Actions, and Recommendations, supplemented by highlights of the reporting from each of the Nordic countries).
2. Full country reports on the bioeconomy, activities and available infrastructures from each of the Nordic countries, including Greenland and the Faroe Islands.
3. A consultancy report (authored by Matis, Iceland) on business needs and opportunities within the bioeconomy, upgrading biological resources from agriculture, forestry, and fishery, as well as from industrial organic side streams and household waste.

Upgrade of biomass from waste fractions from agriculture, forestry and fisheries has huge potential for improved use of the biological resources. Globally, approximately 50% of the primary production is still not utilized, but wasted. Conversion of waste streams to products of higher value is the basis of the new bioeconomy. Conversion of biomass to bioenergy is well described and the process is already developed for upscaling and commercialization. However, development of biobased products into products of higher value, such as healthy food and feed ingredients, speciality chemicals and functional materials is still in its early stages. Plant fibers are not the only component to be exploited; also proteins, lipids, lignins etc. have great upgrade potential. However, competitiveness of the biobased products is crucial to ensure fair conditions of commercialization of these products compared to existing products on the market.

On the basis of the current status of bioeconomy technologies and value chains, a dual task lies ahead: rapid establishment of biorefineries based on existing technologies to create jobs, improved resource efficiency and more competitive business options; and development of new processes and high value products to gain leadership in biorefining technology, and jobs and market shares also in the years to come. Through a focus on strengthening Nordic cooperation we can address both tasks in a more effective and innovative way. This report provides a better basis for how this can be done sustainably, smart and fast.

The Nordic Bioeconomy began differently from in most countries in the world. Right from the very start, most of the Nordic countries have not focused only on biofuel. The most significant trend noted has been the build up of competence and technologies in both academia and business R&D to enable valorization of side streams from primary production and from the bio-industrial sector. In this way a platform is being built to upgrade biomass to higher value products such as food and feed ingredients, chemical building blocks and new functional materials, cosmetics etc.

The second trend reported by the project is that all the public research funding agencies in the Nordic countries have had major program activities dedicated to developing knowledge, know-how and technologies of relevance the yellow biorefinery, to start with, and later also for the green and the blue biorefinery and for upgrade of waste.

A third trend is a focus on both the business potential of increased resource efficiency and on environmental and economic sustainability. Further, the potential for generating new jobs and stimulating rural development through for growing the bioeconomy has also been among the drivers.

A fourth trend is that the Nordic Bioeconomy over the last five to ten years has been a development priority of all the major Nordic players (Nordic Council of Ministers (NCM), Nordic Joint Committee for Agricultural and Food Research (NKJ), Nordic Forest Research (SNS), NordForsk, Nordregio, Nordic Energy Research (NEF), Nordic Forestry and the Nordic Fisheries and Aquaculture cooperation (AG-Fisk) and The Environment and Economy group (MEG) under The Nordic Council of Ministers for the Environment).

This NCM Bioeconomy report also highlights several areas and aspects of importance for the bioeconomy that so far have been insufficiently addressed and followed up. The implications are that the inherent potential of the bioeconomy for generating of new jobs, development of rural and coastal areas have not yet been fully exploited.

The framework conditions for building business in the area of upgrade of side streams and waste have not been updated and mainstreamed to allow for efficient and successful development of the bioeconomy (e.g. several regulatory obstacles are slowing down this development, and incentive structures towards creating markets for more sustainable and resource efficient biobased products are not in place).

Furthermore, available and accessible infrastructures for upscaling of biorefinery technologies and processes are very limited. The shortcomings especially within pilot scale test centers for upscaling of technologies and processes pose significant obstacles to the further efficient development of the bioeconomy. This leads to suboptimization of the resources invested (almost all players have to invest in upscaling facilities). The mechanism of sharing best practice within and between the Nordic countries is also taking place only to a very limited extent.

Another observation from this project is that Nordic project initiatives have only to a very limited extent led to continued Nordic collaboration beyond the designated Nordic programs. The university partners primarily collaborate with nationally based industries. And industries most often seek nearby university partners. Basically this means that we have not moved forward and harvested synergy to the level to which it could have been done. Such suboptimized use of opportunities for sharing best practice and building critical mass and momentum leaves room for improvement.

The list of recommendations specifically addresses how such shortcomings of the development of the Nordic Bioeconomy can be overcome, preferably already within the short and medium term, for long term benefit. If collaboration between the Nordic countries is increased, we can all move ahead faster. The tangible outcome of faster implementation of the bioeconomy is improved resource efficiency, more new jobs (also in rural areas), increased international industrial competitiveness, and timely development of improved biorefinery technologies, as a foundation for technological leadership and technology export. In this way the Nordic countries will also contribute towards a more sustainable world in general.

This report is part of the Nordic Prime Ministers' overall green growth initiative: "The Nordic Region – leading in green growth" – read more in the web magazine "Green Growth the Nordic Way" at www.nordicway.org or at www.norden.org/greengrowth

1. Introduction

The Nordic prime ministers have placed green growth high on the political agenda in order to deal with challenges of combining growth, competitiveness and climate change. By working together, the Nordic region will carry more weight, build a stronger technology base, gain greater market share, and make a stronger political impact at international level.

The Nordic prime ministers decided on 1 November 2011 to launch eight initiatives to boost green growth more effectively. Developing Nordic test centers for green solutions is one of the prime ministers' eight initiatives. Against this background the prime ministers requested the energy ministers in collaboration with the ministers for trade, research, transport and agriculture

- to study the opportunities for developing Nordic co-operation around existing national schemes so that energy technologies can be tested and developed on a large scale
- to study the opportunities and added value to be derived from establishing new joint Nordic test and demonstration facilities.

In 2013 Kontigo mapped the existing green energy test facilities and demonstration sites in the Nordic countries, commisioned by the Ministers of Energy (Kontigo, 2013 unpublished). The aim of the present report is to supplement the previous mapping with information on existing biorefineries not focusing exclusively on energy, and to include other bioeconomy relevant test centers, to obtain a complete overview of the Nordic Bioeconomy, and of the potential for developing added value.

The project was coordinated with the Icelandic chairmanship program NordBio, and preliminary results were presented by project Chairman, Professor Lene Lange, at the conference "Arctic Bioeconomy – Focus on West-Nordic Countries" held in Reykjavik, Iceland in November 2014. The project was also presented under the headline, "Key role for biorefineries in the circular bioeconomy", in Green Growth Magazine (www.nordicway.org) in June 2015. The recommendations have further been presented to the Nordic Prime Ministers at a meeting in October 2015 (http://urn.kb.se/resolve?urn=urn:nbn:se:norden:org:diva-4098).

The composition of the project group is given in Table 1. The project group consisted of prominent scientists within the field of bioeconomy as well as government officials from all the Nordic countries. Valuable information was also contributed by expertise in the area from Greenland and the Faroe Islands.

Table 1: Project Partners in "Development of the Nordic Bioeconomy – NCM reporting: Test Centers for Green energy solutions, biorefineries and business needs"

Name	Association	Country	Contact info
Lene Lange (Coordinator)	Technical University of Denmark, until 1 June Aalborg University	Denmark	lenl@kt.dtu.dk
Niels Gøtke	Ministry of Higher Education and Science	Denmark	nigoe@fi.dk
Sigrún Elsa Smáradóttir	Matis	Iceland	sigrun@matis.is
Guðmundur Ó Hreggviðsson	Matis; University of Iceland	Iceland	gudmundo@matis.is
Alexander Wentzel	Sintef	Norway	Alexander.Wentzel@sintef.no
Marith Valseth	Innovation Norway	Norway	marit.valseth@innovasjonnorge.no
Kristiina Hildén	University of Helsinki	Finland	kristiina.s.hilden@helsinki.fi
Miia Mäkelä	University of Helsinki	Finland	miia.r.makela@helsinki.fi
Juho Korteniemi	Ministry of Employment and the Economy	Finland	juho.korteniemi@tem.fi
Eva Nordberg Karlsson	Lund University	Sweden	eva.nordberg_karlsson@biotek.lu.se
Stefan Källman	Ministry for Rural Affairs	Sweden	stefan.kallman@regeringskansliet.se

Terms of reference

The aim of this project was to strengthen and support the Green Growth Initiatives by analyzing and mapping the opportunities and added value for Test Centers in the area of biorefineries and business. On the basis of this study further initiatives and policy recommendations can be made.

The aim was also to investigate further Nordic business needs and the possibilities for increased cooperation regarding green energy Test Centers, and demonstration and pilot projects including biorefineries.

The aim includes use of results by the previous Icelandic chairmanship, the current Danish Chairmanship and the coming Finnish chairmanship, the Nordic countries, Nordic institutes, the Nordic Bioeconomy Panel, relevant sectors/industries and by the taskforces for making the bioeconomy a reality.

The bioeconomy aims at better use of natural resources through a cross-sectoral and holistic approach. This requires a focused strategy, improved framework conditions and strengthened incentive structures for biorefinery pilot projects and test centers. Biorefining is the sustainable processing of biomass into a spectrum of biobased products (food, feed, chemicals, and materials) and bioenergy (biofuels, power and/or heat).

1.1 Background

A platform for development of the new Nordic bioeconomy was initiated in 2011 with the report on "The Nordic Region – leading in green growth" (http://norden.diva-portal.org/smash/get/diva2:702359/FULLTEXT01.pdf) by the Working Group for Green Growth under the Nordic Council of Ministers.

The previous and current holders or the chairmanship of the Nordic Council of Ministers, Sweden, Iceland, Denmark, and the upcoming Finnish chairmanship have been major champions of the development of the bioeconomy in the Nordic context. In 2012 the Nordic Ministers of Fisheries, Aquaculture, Agriculture, Food and Forestry, meeting in Trondheim, emphasised in the "Nidaros Declaration" (http://www.norden.org/en/nordic-council-of-ministers/council-of-ministers/nordic-council-of-ministers-for-fisheries-and-aquaculture-agriculture-foodstuffs-and-forestry-mr-fjls/declarations-statements-and-decisions/nidaros-declaration) that the primary production and food industries as well as efficient and sustainable use of natural ressources and waste streams are key factors for economic green growth. This line of thinking was continued at the Nordic Prime Ministers Summit in Iceland in 2014, where the bioeconomy is named as one of two specified focus areas of Nordic cooperation (http://www.norden.org/en/news-and-events/news/nordic-top-priorities-on-prime-ministers-summit).

The discussion of the Nordic Bioeconomy was initated and carried forward by a number of Nordic initiatives, for example by the Nordic Joint Committee for Agricultural and Food Research (NKJ) in 2011. Since 2011 NKJ has taken several initiatives to discuss the Nordic bioeconomy and to start up specific and tangible Nordic bioeconomy initiatives. Furthermore, the Nordic Forest Research (SNS) and the Nordic Forestry and the Nordic Fisheries and Aquaculture cooperation (AG-Fisk) have been heavily involved. Several initiatives taken by NCM within the frame of ScanBalt Forum have also significantly forwarded and expanded the scope of the bioeconomy within both the Nordic and the Baltic region, eg. NCM is Priority Area Coordinator (PAC) for Priority Area (PA) Bioeconomy.

At EU level the bioeconomy discussion was initiated with the EU Bioeconomy strategy in February 2012, which was communicated and discussed under the Danish EU chairmanship. The next step was the establishment of the European Bioeconomy Panel in 2013 and the start of the Public Private BioBased initiative, BBI, Joint undertaking in 2014 (EUR 3.7 billion in all).

Internationally, a number of OECD and UNEP reports on the bioeconomy also forwarded the discussion, and not least, substantial research and development efforts have been carried out, supported by national, Nordic, EU and global (primarily in US, China, and South America) research, innovation and business development programs. OECD first used the concept bioeconomy in 2006, but has since then chosen to use the term Green Growth. In the present NCM report and in for example Horizon 2020, the term bioeconomy is used. The bioeconomy is a part of green growth, but the two terms are not synonymous.

The focus of the Nordic Green Growth was a common electricity market, development of common standards, stimulating green public procurement, introduction of new ways of handling waste materials, stimulating environment and climate friendly policies and regulations, and a coordinated investment plan.

One of the programs under the Nordic Ministers "Green Growth" initiative, "Developing Nordic Test Centers for Green Solutions" resulted in 2013 in the report "Green Growth, mapping of green energy test facilities and demonstration sites in the Nordic countries" (Kontigo 2013, unpublished). An overview was provided of the Nordic green energy test facilities (DK 15; S 12; N 9; F 8; I 1) with a focus exclusively on renewable energy. The conclusion from this was that increased collaboration among Nordic counties was needed and joint investments in new test facilities were recommended. Therefore the aim of the present report is to supplement the mapping by for example Kontigo with information on existing biorefineries but not focusing exclusively on energy; other test centers relevant to the bioeconomy are included to obtain a complete overview of the Nordic Bioeconomy and the potential for developing added value from biomass.

In 2014, the status report "Nordic Region – leading in green growth" (Nordic Council of Ministers, http://norden.diva-portal.org/smash/get/diva2:732564/FULLTEXT02.pdf) was published. The focus and conclusions from 2011 were elevated to become a Nordic Prime Ministers initiative, embracing essential recommendations of Nordic Green Growth, far broader than just energy; however, the report still did not include specific initiatives within the new bioeconomy.

In 2014, a new Nordic report was published that focused specifically on the potential of the bioeconomy based on the idea of innovation: "Creating value from bioresources, Innovation in Nordic Bioeconomy" (Rönlund *et al*. 2014). The focus of this report was on biobased production of bioenergy but also on biobased production of renewable building blocks for chemicals and materials, substituting for fossil-based, chemicals and materials. The approach in this report was on mapping framework conditions for "Innovation, fundamentals, assets and enablers". For the first time this aspect of green growth was connected to the entire bioeconomy sector, including value from primary production (agriculture, fishery and forestry; as well as the food industry, forestry industry, bioenergy and biofuels).

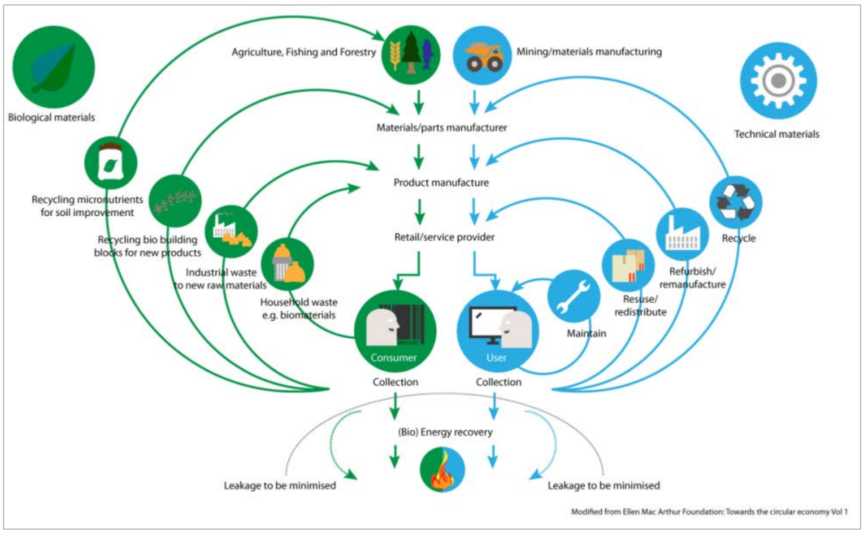
On the basis of this overview (Rönlund *et al*. 2014) it was concluded that the bioeconomy in total made up 10% of the total economy in the Nordic countries (varying from 18% in Iceland to 6% in Norway). Of this, the new biobased bioeconomy (made up of value generated from conversion and upgrade of byproducts, crop residues, and waste streams) constituted approximately one tenth of the total bioeconomy, namely 1% of the total Nordic economy. An inspiring catalogue of cases was included in the report.

As the above indicates, to a large extent most of the bioeconomy activities have been developed outside of the developments within the Green Growth Initiative. This is mostly because few (or none) of the eight focus areas of the Green Growth Initiative embrace and address the inherent potential of the bioeconomy for improved resource efficiency, job creation, economic development (also in rural areas) and strengthened industrial competitiveness, including technology export and technological leadership.

1.2 Scoping of the new Bioeconomy, a part of the Circular Economy

Among the Nordic countries the approach to develop the bioeconomy has been different to the general approach in the EU. Until recently, most of the discussions in the EU have been almost exclusively focused on biomass for bioenergy. However, it is noteworthy that the bioeconomy in for example Iceland and Norway has focused from the start on upgrade of organic resources to higher value products such as food and feed. Similarly, the focus in Finland and Sweden has included biobased chemicals and materials and not only biofuel production. In Denmark, however, much like in the rest of EU, for a long time the focus was primarily on utilizing left over bioresources, such as crop residues, for bioenergy, biofuel, electricity and heat. Figure 1. illustrates that biological resources can be recycled and upgraded as complex biological materials, as building blocks for making new products, or as minerals for soil improvement. Only what cannot be used for other purposes should be combusted.

Figure 1: In the circular bioeconomy biological materials can be upgraded and reused in many types of new value chains to obtain more primary products from the raw materials. Complex molecules such as proteins from industrial side-streams and household waste can be recovered as building blocks for new microbial products, as advanced biofuels, biomaterials and biochemicals, and by recycling nutrients back to the soil. What remains after all usable elements have been utilized can be converted through combustion into electricity and heat (bioenergy recovery)

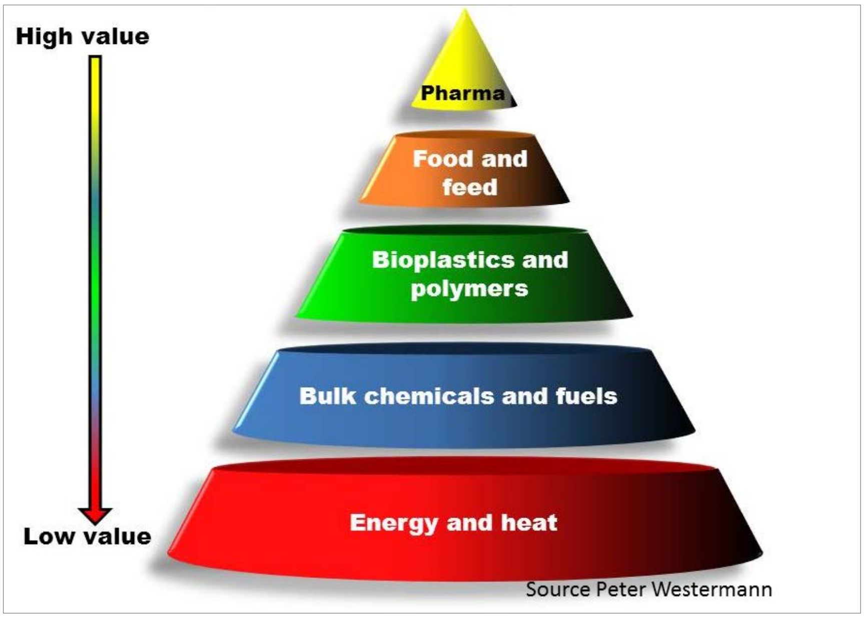


Source: ERST Report, Lange & Remmen, 2014.

Right now, throughout the Nordic countries and in the EU, the focus is on value cascading to unlock the full potential of the biomass by producing a series of products from the biomass, recovering the most valuable products before they are damaged by the pretreatment, and processing for recovery of the products of lower value.

The new global developments in supply of fossil energy (increased amounts are available e.g from shale gas and additional supplies of methane) and of decreasing fossil energy prices has, however, had an impact on the entire bioeconomy area. This has resulted in a new focus emphasizing that bioresources should be exploited to their full potential and provide a basis for value cascading (Figure 2), where the most precious products are taken out first (e.g. nutraceuticals, high value metabolites, and feed and food ingredients), and then the sugar platform of cellulose fibers (and leftover fractions) are used for production of bioenergy. A special focus on the need for a renewable alternative to transport fuel has also been strengthened. The current vision is that all the potential of the biomass feedstock can be exploited in an integrated biorefinery approach, resulting in a commercially viable biobased industry with competitive prices, including for biofuel, because the cost of the feedstock and biorefinery processing are paid for by the higher value product value chains.

Figure 2: Biomass cascade: high value compounds at the top, residual biomass for production of low value energy, electricity and heat at the bottom



The second global trend is a focus on the speed of the development of the biorefinery technologies needed for upgraded use of bioresources. Previously we concentrated on whether the biomass feedstock was available. Now we know from global overviews that at least one third of all primary production ends up as waste (http://www.fao.org/food-loss-and-food-waste/en/). It is an important issue for agricultural, forestry and fishery practice and logistics to ensure that the biomass is being upgraded to create value; and it is an issue to develop not only straw- and stover-based biorefineries but also to develop a broad range of other types of biorefineries, which can handle different types of biomass: the Blue Biorefinery on marine biomass, from fish waste and discard; and from macroalgae; the Green Biorefinery, from green grass and other fresh/green plant materials; the Yellow Biorefinery, from recalcitrant yellow biomass, straw, stover and wood; the Grey Biorefineries from (clean!) agroindustrial sidestreams; the biorefinery with household waste as feedstock; and the Brown Biorefinery, based on sludge from waste water treatment for example.

The third new focus in development of the new bioeconomy is on the need for using our bioresources more responsibly. The use of our available bioresources has become part of the global responsibility discussion: can Europe continue to base its meat production on imported protein? Maybe we should have a new focus on upgrade of unexploited local protein resources? Important projects focusing on developing alternatives to imported soya protein have already been conducted: projects headed by Knud Tybirk "Proteins the green gold of Baltic Sea region bioeconomy" (http://www.norden.org/en/theme/nordic-bioeconomy/bioeconomy-in-the-baltic-sea-region/realizing-bioeconomy-in-the-baltic-sea-region/networks/proteins-the-green-gold-of-baltic-sea-region-bioeconomy) and by Fredrik Fogelberg, JTI "Nordic-Baltic Plant Protein Arena for Improved Food/feed Security" (http://www.norden.org/en/theme/nordic-bioeconomy/bioeconomy-in-the-baltic-sea-region/realizing-bioeconomy-in-the-baltic-sea-region/networks/fact-sheet-nordic-baltic-plant-protein-arena-for-improved-food-feed-security/view).

The next and recent development in the bioeconomy discussion focuses on development of the bioeconomy to unlock the full potential of biological resources – in a sustainable manner – as one of the most interesting new areas of economic growth and development; maybe the single most important area of growth that includes local development, and leads to development in both rural and coastal regions. The reasons for such predictions are that the new bioeconomy will provide a substantial number of new jobs. Jobs in primary production, jobs in logistics of handling the biomass, jobs in constructing the new biorefineries and jobs in running the new biological production. Biological production, where value-added products are produced by microorganisms or recovered from plant biomass, converted by microbial enzymes, is the new and most prominent change in global manufacturing. Biological production requires access to technology and skilled and competent manpower. Furthermore, the jobs are generated locally becasue the biorefinery cannot be easily outsourced since it builds on locally available feedstock in the form of bulky biomass, crop residues, byproducts and waste streams.

The basis of the bioeconomy was already formed by industrial biotechnology. The technologies, processes and products of industrial biotechnology also form the foundation of core technologies for the bioeconomy. Europe was in the absolute forefront, forming and building the global market for enzymes and ingredients (e.g. Novozymes, Danisco/now DuPont, and DSM). This has resulted in use of European technologies as the basis for the biorefinery processes in all areas of the world where the bioeconomy is developing and unfolding its potential. The creation of new know-how, technologies and processes is still a very active field in Europe. However, the EU is not taking the global lead in developing the new bioeconomy and biobased industries. Strengthening collaboration and coordination in the EU and among the Nordic countries has the potential to accelerate the development of creating value by upgrade of hitherto underexploited biological resources.

A significant part of growth in the bioeconomy is taking place in the emerging market-economy countries. Collaboration within the field of biorefinery and upgrade of bioresources with the BRIC countries (Brasil, Russia, India, and China) provides an interesting business opportunity: integrated partnerships among Nordic (and European) public research and specialized European industries can provide a strong basis for collaboration with emerging market-economies. There is the option to develop the entire bioeconomy field faster by collaboration through using our technologies on different types of biomasses, and thus providing a basis for export of technology export and specialized goods. The emerging market-economies can transform their economies faster in the direction of improved resource use efficiency and we can benefit by increased trade and technology export.

As a prerequisite for achieving such gains and an increase in competitiveness, it is necessary to create well thought through strategies with regard not just to technologies but also to knowledge management, including both increased knowledge sharing AND smarter ways not only knowledge protection but also of faster and smarter use of new knowledge.

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1.3 Conclusions

This report on the status of the bioeconomy in all the Nordic countries clearly demonstrates that the bioeconomy has developed more rapidly in both R&D and business than was previously expected and described. However, a few bottlenecks for continued development have been identified: 1. Lack of ambition in the political goals for level of upgrade of underexploited bioresources, and 2. Slow establishment of a stimulatory framework for the new biobased industries.

There is a surprising lack of open access test facilities available in the Nordic countries for upscaling new processes and products. Such open access facilities need to be able to accommodate different types of stakeholders along the entire value chain, and different types of business segments, for development of a range of processes and products from diverse bioresources. Coordinated use of available test facilities and establishment of new test facilities in countries and regions lacking such facilities could provide a shortcut to even stronger development of the bioeconomy in the Nordic countries. This potential is not yet exploited.

The highly diverse bioeconomy, already initiated in the Nordic countries, provides a promising platform for further development of the entire bioeconomy sector. By unlocking the full potential of sustainably produced bioresources, producing a cascade of biobased products, the Nordic countries can gain tremendously not only in sustainability and improved resource efficiency but also in creation of jobs, in rural and coastal development, and not the least with regard to increased technology export and achieving technology leadership. Such Nordic development can also benefit the rest of the world and provide a bridge for the Nordic countries to collaborate with the growth economy countries.

The profile of the Nordic version of the bioeconomy is starting to emerge: The headline of the bioeconomy discussions in the Nordic countries has also primarily been: “Biomass to Bioenergy”. However, in the Nordic countries the generation of new knowledge, novel technologies, improved processes, and investments has also been targeted at a spectrum of biobased products, advanced biofuels, biochemicals, biopolymers, and not the least feed and food ingredients, cosmetics and health-promoting products.

The report gives many Nordic examples of different types of high value biobased products derived through biorefining of diverse under-exploited bioresources. This adds a dimension of diversity to the profile of the Nordic version of the bioeconomy: the blue biomass (e.g. algae and fish waste); the yellow biomass (straw and wood); the green biomass (green grass, clover, hemp etc); the grey agroindustrial biomass (side streams of slaughterhouse and dairy industry); and the brown biomass (sludge from e.g. waste water treatment).

Furthermore, advances in biorefining also depend on having superior fractionation technologies and recovery processes, such as for the recovery of complex proteins and metabolites, followed by separate development of the main components. Such aspects are also covered in the current Nordic Biorefinery mapping.

Most importantly, the future Nordic biorefineries will include both large centralized infrastructures, providing economy of scale for bulk, low value products, and decentralized, smaller units for more specialized production of higher value products. Decentralized units may, for example, be placed at the industrial plant itself for "end of the pipe" upgrade of industrial side and waste streams. Business development and commercialization of biobased products in the Nordic countries will involve start-up companies, small and medium sized enterprizes (SME's), middle size industries and larger, established businesses. Clusters and collaboration between matching biorefineries among the Nordic countries are yet to be fully exploited.

1.4 Trends and Actions

The new bioeconomy is one of the strongest cards for Europe and the Nordic countries for implementing the vision of a smart, sustainable and inclusive society. The bioeconomy has the potential for strengthening the global competitiveness of a broad spectrum of industries. These include agriculture, forestry, and fisheries, as well as strengthening the competitiveness of biobased industries, green platform chemicals, materials and biopolymers, and not the least both new and existing food and feed ingredients and processing industries. Competitiveness will be achieved through improved resource efficiency, upgrading to higher value, and profiling the Nordic Countries as green and sustainable in primary production, processing and products.

Strong positioning of the biobased industries in the Nordic countries could also lead to increased industrial competitiveness as a result of harvesting the benefits of a circular economy derived from lower costs of transport, logistics and energy. Furthermore and most importantly, the development of a stronger bioeconomy could lead to significant steps forward in job creation, new export opportunities and in achieving and maintaining technological leadership in for example biological production – the new type of manufacturing.

Some European countries have already taken the step of investing in commercial scale biorefineries, where crop residues and agricultural side streams are converted into products such as transport fuel, animal feed, soil improvement products and biogas. However, the bioeconomy in the rest of the world is advancing more rapidly than in Europe. It is thought provoking that the majority of upscaling in the global bioeconomy is being achieved using knowledge that was generated by European research. We are putting the potential of Europe at a competitive at risk if we do not move ahead rapidly, making good use of our competitive advantage. Use it or lose it.

The hypothesis of this report is that rapid development of the Nordic bioeconomy, using increased collaboration and sharing of upscaling of biorefinery infrastructures and test centers, can contribute to the more rapid advance of all the individual Nordic countries. We can improve overall societal and environmental gains by exploiting the full potential of a strong bioeconomy through efficient coordination and maximum use of synergies from now on.

The Nordic countries have a very strong foundation for the successful implementation of new value chains within the bioeconomy: strong, knowledge-based primary production within agriculture, forestry, and fisheries and aquaculture; very efficient agroindustrial, feed, food and non-food industries; a globally leading industrial biotechnology sector; a globally leading pharmaceutical industry built on biological production; a well regulated waste handling sector; and a legal framework which allows introduction of products from new value chains based on biomass, waste and side stream conversion.

However, more momentum is required within the following areas: improved framework conditions for stimulating markets for biobased products and setting goals for increased bioresource upgrading; utilization of biomass to its full potential by implementing value cascading principles, developing all components of biomass to their highest levels; development of both small, decentralized biorefineries and larger, centralized biorefineries requiring large investments.

1.5 Recommendations

1. Strengthen the bioeconomy as an area of high priority for Nordic collaboration

Maintain the development of the Nordic bioeconomy as an area of priority for collaboration between the Nordic countries. Involve the upcoming Nordic Bioeconomy Panel in building momentum for sustainable upgrading of underexploited Nordic bioresources.

2. Collaborate to achieve and maintain a Nordic competitive edge in the bioeconomy

If we work only nationally, we risk moving too slowly, one biorefinery segment at a time, and thus losing our competitive advantages of high education level, relevant professional expertise in other sectors, and abundant biomass resources. Nordic collaboration can be used as a springboard for enabling each of the Nordic countries to develop several segments of the bioeconomy. When moving fast we create options for technology leadership in areas that are still hardly developed or not yet developed internationally.

3. Open Nordic access to more bioeconomy-relevant test facilities

Integrate open access conditions in Nordic bioeconomy infrastructure programs to allow more efficient use of the publicly supported biorefinery-relevant test facilities across regions and sectors. Sharing infrastructures can be used to speed up commercial development, by well-thought out structures adding value also to competing industries.

4. Coordinate bioeconomy efforts across sector ministries in the Nordic countries

Achieve cross-ministerial coordination of research, innovation and investment plans for development of the bioeconomy. More coordinated, less fragmented support for biorefining R&D, scale-up, demonstration, commercialization, and improved regulatory framework conditions would ensure increased impact of the invested resources.

5. Coordinate Nordic policy and incentive structures for commercializing biobased products

Build incentive structures (e.g. by decrease in waste handling fee if waste streams are more efficiently upgraded and resources recycled to a higher percentage); establish markets for new biobased products (e.g. using blend-in requirements); stable incentives will support new biobased value chain products, made by new or existing industries which commercialize products from residues from fisheries, aquaculture, forestry and agriculture as well as from upgrading of waste water sludge and municipal waste.

6. Combine Nordic efforts to update the EU regulatory framework for biobased products
Join forces across the Nordic countries to spearhead progress within the EU and update regulatory frameworks to enable timely and affordable commercialization of new and safe biobased products.

7. Develop a strategy for the Nordic bioeconomy to stimulate rural development
Develop a common strategy for stimulating the Nordic bioeconomy in a manner where job creation and development of rural (and coastal) areas are given high priority. Establish technologies and processes for a new generation of small-scale biorefineries, upgrading local resources.

8. Establish Nordic SME-designated bioeconomy relevant instruments
Develop efficient SME clusters around biorefineries, thus simplifying logistics and cutting costs of transport by proximity, and most importantly harvesting synergy by using each other's side streams and energy within the cluster (embracing small, medium-sized and large industries).

9. Inter-Nordic collaboration to have biorefineries included in Juncker's EU Investment plan
Join forces across the Nordic countries to have biorefineries and other bioeconomy relevant infrastructures included on the list of investment objects both for the European Commission's Investment plan (Juncker) and for national capital (e.g. pension funds).

10. Formulate ambitious Nordic strategies for international collaboration within the Bioeconomy
Exploit the strengths of the new Nordic bioeconomy to establish public/private international collaboration (within the EU, but also with e.g. BRICS countries and Africa) to provide leadership and technology export within biorefinery upgrade of bioresources.

Recommendations 11–14 below are additional recommendations specifically formulated based on the information gathered in the survey of biorefining industrial needs and opportunities, Chapter 3. The recommended actions outline the biorefining industry's major requirements for *improvements and support to create the full value from developing the business sector of the new bioeconomy.*

11. Improving governmental framework and support

The Nordic biorefining industry needs clearer policies and a transparent and stable regulatory environment. This applies both within the region and in Europe as a whole. The biorefining industry needs similar initial government assistance, funding and incentives to those enjoyed earlier by the green technologies. Government support should focus on: increased funding of research in biorefinery applications and biotechnology solutions; stable subsidization of innovative biorefining applications; creation of markets for biorefining products; support for biorefineries through various tax incentives and by public promotion of the concept of the Nordic bioeconomy; investments in biorefining demonstration facilities.

12. Bridging the gap to demonstration

The technical and financial risks of Nordic biorefining industries, associated with scale-up and demonstration of innovative technologies, need to be reduced through public investments. Several biorefining demonstration sites need to be built within the region and should be flexible to suit different applications, but also need to be designed for specific processing techniques and bioresources. The facilities should be government run and available to the industry at low rental fees.

13. Governmental co-investments for commercialization of innovative biorefineries

Increased public investments in the commercialization of innovative and developed biorefining applications are required to stimulate private investments, through reducing the risk in the industry and attracting private investors. Further commercialization of different biorefining applications will give the industry needed market experience and the opportunity to demonstrate the potential of the biorefining sector. Political prioritization and focus on the initial commercialization of selected biorefining applications and products is recommended, in consultation with biorefining stakeholders. The prioritization should not be biased towards production of bioenergy products.

14. Setting up a strong Nordic biorefining innovation center

There is a clear need for a strong and active co-Nordic biorefining innovation center providing a range of support to the industry. The support should be focused on: expert assistance on commercialization, marketing, product registration, protection of intellectual property rights and the global regulatory environment; provision of regional overviews of existing applications, product developments, test facilities, and collaboration and funding opportunities; feasibility mapping of biorefining products and market needs.

1.6 Bioeconomy, activities and infrastructures in the Nordic countries

1.6.1 Latest news on the Nordic bioeconomy, May–October 2015

Norway

The Norwegian national bioeconomy strategy is taking shape. A dialog conference was held in Oslo on 18 June, 2015 with contributions from government representatives and speakers from a wide spectrum of relevant Norwegian industry, institutes and academia as well as representatives from other Nordic countries. Subsequently, a total of 40 invited papers was submitted and published until 15 August, 2015, from a wide spectrum of Norwegian stakeholders, providing additional input to the final strategy documents, scheduled to be finalized by the end of 2015 (www.regjeringen.no/no/aktuelt/regjeringens-biookonomistrategi/id2425964/).

NIBIO, the Norwegian Institute of Bioeconomy Research, was established on 1 July 2015 as a merger between the Norwegian Institute for Agricultural and Environmental Research (Bioforsk), the Norwegian Agricultural Economics Research Institute and the Norwegian Forest and Landscape Institute. The goal of the new Institute with its approximately 700 employees is to contribute to food security, sustainable resource management, innovation and value creation through research and knowledge production within food, forestry and other biobased industries (www.nibio.no).

Finland

The Finnish Government will invest EUR 300 million to promote the bioeconomy and clean energy solutions for 2016–2018 as one of its so-called spearhead projects. This will be implemented for example by promoting research and innovation and by launching a number of pilot and demonstration projects. Another goal is to prepare and implement a national strategy for the development of blue bioeconomy in 2016–2018. The ultimate aim for Finland is to be a forerunner in the bio- and circular economy and clean tech by 2025. The Riihimäki Circular Economy Village, which will be completed in 2016, is the first concrete step in Finland towards the circular economy. As the part of the complex, EUR 14.5 million are being invested to construct the biogas facility that will have a production potential of 50 GWh/year. In addition, nutrients such as nitrogen will be recovered.

Iceland

A national Bioeconomy strategy is being prepared for Iceland. Iceland will take on the secretariat of the West Nordic bioeconomy panel that holds its first meeting this fall. The priority program under the Icelandic chairmanship of the Nordic Council of Ministers "NordBio" is under development and the results will be represented at the program's final conference on 5–6 October 2016 in Iceland. One aspect of NordBio is to initiate a Nordic Bioeconomy panel, which is expected to be formed later this year. In September it was announced that Iceland will host the next World Seafood Conference on 10–14 September 2017, and the theme of the conference will be Growth in the Blue Bioeconomy. Private initiatives are increasing in the development of the Icelandic Bioeconomy; for example, further investments in seaweed biorefinery are under preparation, and a product by Kerecis, an Icelandic biotech company, was named "most interesting wound care products of 2015" by Wound Source magazine.

Faroe Island

A successful Blue Bioeconomy conference was held on the Faroe Islands this summer, and the first meeting of the West Nordic bioeconomy panel will take place on the Faroe Islands this fall. Furthermore, the Faroe Islands will also take part in the Nordic bioeconomy panel.

Greenland

Greenland participates in the West Nordic bioeconomy panel that holds its first meeting this fall as well as the Nordic bioeconomy panel. Increased collaboration between Greenland and Iceland in the field of Bioeconomy is being discussed.

Sweden

In Sweden a national research and innovation strategy (formulated by the Swedish research council Formas) is being implemented, and a national bioeconomy strategy is still under preparation. In this context, during autumn 2015 the government initiated the work of formulating a national forest strategy which will optimize the possibilities of forests to contribute to a sustainable development of Swedish society.

Ongoing innovation activities include the strategic innovation area “Bioinnovation” whose vision is that “Sweden will have made the transition to a biobased economy by 2050”. Bioinnovation is a cross-industry initiative, bringing together 60 actors from industry, academia, institutes and the public sector. The innitiative has funding to develop strong, competitive and innovative materials, products and services based on renewable raw materials. One project expected to start during autumn 2015 is “From lignin to value added biobased fuels and chemicals”.

Denmark

The National Bioeconomy Panel published its recommendations for new value, including from green biomass, in September 2015. The concept includes: grass/clover as feed stock for higher yields and less environmental impact from prolonged growth seasons compared to cereals; use of green biomass for development of locally produced protein-rich animal feed; realization of the full potential of biomass value cascades to include production of animal feed dietary fibers (http://naturerhverv.dk/fileadmin/user_upload/NaturErhverv/Filer/Indsatsomraader/Biooekonomi/Groen_biomasse/Anbefalinger_groenbiomasse_sept2015.pdf). During the fall the large Danish Innovation Fund, BioValue SPIR consortium, will test and optimize a newly constructed pilot plant for extracting proteins from green biomass. The amount of protein that can be extracted from different types of green biomass will be quantified and quality parameters such as amino acid composition will be analyzed for the soluble and the pulp fractions. Feeding trials, quality assessment, and innovation in process upscaling all need to be investigated to substantiate the business case. Innovation is also taking giant steps forward on critical issues of plant biomass processing as such understanding dewatering concepts and separation of components. MEC, the Maabjerg Energy Center, is approaching full implementation as an integrated bioenergy biorefinery producing biogas, bioethanol, and electricity/heat. It is recommended that the biomass-based biofuel market is stimulated by implementation of the EU directive on blend in of (2.5%) 2G biofuel in gasoline.

1.6.2 Norway, highlights

The bioeconomy landscape in Norway is characterized by the availability of a diversity of land- and marine-based biomass in the country, in particular from forestry, seaweed, fisheries and aquaculture. Many companies of all sizes produce and commercialize products based on these bioresources. Several large companies such as FMC Biopolymer AS (part of FMC Health and Nutrition, producing alginates and other high value products from natural seaweed along the Norwegian coast), Cambi AS (technology supplier for diverse biosolids and biowaste to biogas and fertilizer products by anaerobic digestion and thermal hydrolysis) and Norske Skog ASA (wood to paper and byproducts) perform biorefining and commercialize biomass-derived products at significant scales. The most significant player in integrated commercial biorefining in Norway is, however, Borregaard AS. Borregaard operates one of the world's most advanced and sustainable biorefineries in Sarpsborg, Norway. In integrated processes, lignocellulosic biomass from wood and agricultural waste is utilized and converted into multiple products, including speciality cellulose, ethanol (20 million litres/year), vanillin (world leading supplier), lignin/lignosulfonates (>50% global market share) and bioenergy. About 90% of the incoming lignocellulosic biomass is converted to marketable products.

Publicly financed biorefinery infrastructures

A number of publicly financed biorefinery infrastructures exist in Norway. Important national centres and infrastructures for biorefinery technologies and the bioeconomy are the Norwegian Centre for Bioenergy Research in Ås, the Norwegian Biorefinery Laboratory NorBioLab in Trondheim and Ås, and the National Facility for Marine Bioprocessing NAMAB and the Barents Biocentre Lab in Tromsø. Equipment at these centres is publically available within the framework of research projects in collaboration with the participating institutions. These infrastructures are complemented by several public and private research institutions with dedicated infrastructure for biorefining.

Table 2: Publicly available biorefinery infrastructures, Norway

	Location	Biomass used	Biorefinery/Methodology	Products/Research areas
Central biorefinery infrastructure (hosts)				
Norwegian Centre for Bioenergy Research (NMBU, bioforsk, skog og landskap)	Ås	Lignocellulosics from forestry and agriculture; industrial and municipal waste	Steam explosion unit. 20 L reactor. National biogas facility. Advanced analytical laboratory. NMBU Biorefinery laboratory. Pilot scale laboratory for biomass processing. Milling, hydrolysis (up to 100 L reactors), separation equipment, spray drying. Enzyme production and application facility. Fermentation equipment (2 L to 30 L) for production of enzymes, and downstream protein purification equipment. Reactors for enzymatic saccharification, including high DM reactors (100 mL to 10 L)	Bioheat, biofuel, biogas, sustainability assessments
Norwegian Biorefinery Laboratory (Norbiolab) (PFI, SINTEF, NMBU, NTNU)	Trondheim, Ås	Lignocellulosics from forestry, marine biomass (seaweed)	Biochemical conversion: fermentation facilities up to 50L, up- and downstream processing equipment. Special fermentors for high cell density fermentations and high solid content/high viscosity; anaerobic fermentations; integrated product removal; pervaporation, hybrid distillation-membrane, membrane electrolysis, etc. Thermochemcial conversion: various gasifiers for catalytic conversion to alkanes and heavy alcohols. Slow and fast pyrolysis systems and infrastrcture for upgrading of pyrolysis oils through stabilization, catalytic hydrogenation, decarboxylation. Separation technology: laboratory scale distillation, membrane and pervaporation systems; crystallization systems for recovery of compounds with high boiling points through freezing out technologies and phase separation	Biofuels, platform chemicals
National Facility for Marine Bioprocessing (NAMAB) (NOFIMA)	Tromsø	Marine biomass and residues	Handling of a large variety of biomass, Reactors for hydrolysis, Separators, two/three phase, Liquid phase separation, Purification of lipids, Water filtration (ultra/micro, nano, reverse osmosis), Concentration, evaporators, Mill dryer, hot air, Powder handling, Packaging	Marine ingredients for food/feed and pharma,, hydrolysates, lipids, etc.
Barents Biocentre Lab (BBLAB) (UiT, NORUT)	Tromsø	Marine biomass, diverse marine resources	Molecular and microbiology equipment, Analysis equipment, Preparative equipment, Synthesis equipment. Main aim: bioprospecting for high value products from marine resources.	Marine high value products; pharma, enzymes, etc.

	Location	Biomass used	Biorefinery/Methodology	Products/Research areas
Major biorefinery research organizations				
SINTEF	Trondheim, Oslo	Lignocellulosics from forestry, marine biomass (seaweed), industrial and municipal waste, microalgae	Bioprocess technology platform up to 300L pilot scale, advanced mass spectrometry (MS) platform, high throughput screening (HTS) platform, molecular biology platform for strain development using System and Synthetic Biology, facilities for biorefinery catalyst R&D, gasification rigs, hydrothermal treatment rigs (batch/continuous), torrefaction reactor, pyrolysis/carbonization/combustion reactors, fuel storage and characterization infrastructure, research infrastructure for processing of marine by-products and the cultivation of seaweed/macroalgae and microalgae	Biofuels, platform chemicals, biopolymers, food&feed, industrial enzymes, biopharmaceuticals, process modelling and design, techno-economic analysis
Norwegian University Of Life Sciences (NMBU)	Ås	Lignocellulosics from forestry and agriculture; industrial and municipal waste	Steam explosion unit, national biogas facility, advanced analytical laboratory, NMBU biorefinery laboratory, enzyme production and application facility, pilot scale facility for feed production, food processing pilot plant, animal feed trial facilities. See also: Norwegian Centre for Bioenergy Research	Biogas, industrial enzymes, bioprocess technology, food&feed
Paper and Fiber Research Institute (PFI)	Trondheim	Lignocellulosics from forestry	Pretreatment/pulping equipment (mills, refiners, fibre separation units, boilers), conversion tools (fast pyrolysis, rapid heating displacement reactor, homogenizers and mills for production of nanocellulose, extraction equipment, pellet press), chemical, physical and morphological analytical equipment	Preprocessing technology, energy products, chemicals, material products, e.g. nanocellulose
Telemark University College (HiT)	Porsgrunn	Lignocellulosics, marine biomass, industrial and municipal waste, microalgae	Feedstock pretreatment, lab and small pilot scale bioreactors for biogas production, gasification rigs (together with UIA), microalgae cultivation equipment, modeling tools for process simulations, analytical and characterizing equipment, biorefinery safety	Pretreatment, gasification, biogas, microalgae, process safety
Norwegian University of Science and Technology (NTNU)	Trondheim	Lignocellulosics, marine biomass (seaweed), industrial and municipal waste, microalgae	Multi-fuel reactor for fundamental studies of pyrolysis, gasification and combustion, small scale downdraft gasification rig, lab scale torrefaction facility for pretreatment, engine lab for fuel testing, analysis equipment, modelling of biorefinery related processes, marine biopolymer research equipment for isolation, fractionation, characterization and modification, research infrastructure for plant and microalgae cultivation and handling	Biofuels, process modelling and design, marine polymers, plant science, microalgae

Bioeconomy strategy for Norway

A National Strategy for the bioeconomy in Norway is currently under development and expected to be finalized by the end of 2015. An important feature will be a central office across the different relevant ministries to coordinate this cross-sectoral strategy. In preparation for this new strategy, a conference with key national players in the field was held in the middle of June 2015 (http://www.innovasjonnorge.no/no/Nyheter/innspillskonferanse-for-regjeringens-biookonomistrategi/#.Vaa-1Zgw8by).

One important step towards this new strategy is the establishment of a Norwegian Biorefinery Laboratory (NorBioLab) as part of Norway's national strategy for research infrastructure 2012–2017 (http://www.forskningsradet.no/prognett-infrastruktur/Nationalstrategy-for-research-infrastructure/1253976458361). Also, recently, the Norwegian government announced the founding of a new Norwegian Institute for Bioeconomy Research (NIBIO, see 4.1.3 H, https://www.regjeringen.no/nb/aktuelt/norsk-institutt-for-biookonomi-nibio-opprettes-1.-juli-2015/id2394764/) which will be Norway's largest institute specifically dedicated to bioeconomy research.

In May 2015, the Research Council of Norway announced a total of NOK 900 million for research based innovation for Norwegian industry (http://www.forskningsradet.no/en/Newsarticle/NOK-900-million-available-for-researchbased-innovation-for-industry/1254008982723/p1177315753918). Innovation, sustainability and a more environment-friendly business sector are key themes of this year's call for proposals. NOK 250 million of the total funding available is earmarked for green growth and societal transition, which includes helping supplier-industry companies enter the renewables industry.

1.6.3 Finland, highlights

Finland is a leading user of renewable energy sources, especially bioenergy, in the world. Use of renewable energy sources accounts for a quarter of the total energy consumption and more than a quarter of power generation. Wood and wood-based materials form the largest proportion of these biomass-based resources (Table 3). Forestry, forest-based industries and agriculture are the main bioresources for current biorefineries in Finland. Marine resources are also seen as a promising element in the Finnish bioeconomy but they are still poorly utilized. During Finland's presidency of the Nordic Council of Ministers in 2016, the focus will be on the blue bioeconomy.

The Finnish strategy for the bioeconomy has four strategic goals: to generate a competitive operating environment for the bioeconomy; new business from the bioeconomy; a strong bioeconomy competence base; and accessibility and sustainability of biomass (http://www.tem.fi/files/40366/The_Finnish_Bioeconomy_Strategy.pdf). In Finland the goal is to increase the bioeconomy output up to EUR 100 billion by 2025 and to create 100,000 new jobs. The most recent energy and climate strategy in Finland was approved by the Government in 2013 (http://www.tem.fi/en/energy/energy_and_climate_strategy/strategy_2013). Finland's long-term goal is for a carbon-neutral society, and it is anticipated that an increase in energy efficiency and the use of renewable energy are central in reaching this goal. In order to reach the long-term goals, the Energy and Climate Roadmap 2050 was published in 2014 to serve as a strategic guide in Finland until 2050 (http://www.tem.fi/en/current_issues/pending_projects/strategic_programmes_and_flagship_projects/energy_and_climate_roadmap_2050).

The basis of the new bioeconomy business opportunities in Finland will be novel exploitation of water resources and biomass, and the development of technologies for these resources in order to achieve high added value products and services. The aim is more diverse use of biomass from forestry and agriculture and use of hitherto underexploited biomass resources for new products and materials. The current boundaries between different sectors will also disappear and new value networks will be created. Local interaction between sectors and services will support the exploitation of sidestreams for their efficient use. Currently, the publicly available biorefineries in Finland are Energon, Bioruukki, BioSampo Training and Reseach Centre, Metener Ltd and Sybimar Ltd (see Table 3).

Centres of expertise and a reform of the priorities and operating models of research are needed for competitive bioeconomy. Cross-sectoral activities that create innovative solutions and improve competitiveness are bioeconomy cooperation platforms (Strategic Centres for Science, Technology and Innovation (SHOK) Centres, Innovative Cities (INKA) programme, research cooperation models), and pilot and demonstration projects in cooperation with financial instruments of the EU programming period 2014–2020, and domestic, public and private R&D&I funding. This will require greater cooperation between universities and research institutes, and especially opportunities for business development in bioeconomy besides the research, development and innovation activities.

Table 3: Publicly available biorefinery infrastructures, Finland

Biorefinery	Location	Biomass used	Volume/Value	Biorefinery/Methodology	Product(s)
Energon	Lahti			Energon offers facilities for versatile research of renewable energy and energy efficiency, and also for testing new technology.	The Energon research center can be used e.g. for the development of liquid, gas and solid biofuels.
Bioruukki	Espoo	Research center can be used e.g. for biomass from agriculture and forestry, side streams and waste from industry and municipals.	EUR 10 M investment, further EUR 10–15 M will be invested in future	Gasification and pyrolysis research activities and later expanding in to other research areas	
BioSampo Training and Reseach Centre	Anjala, Kouvola	Organic waste, various biomass		Combined heat and power production burning process	Biogas, electricity, heating, cooling
Metener Ltd, Joutsan Ekokaasu	Joutsa	Local household biowaste and sewage sludge	5,000 tons, waste/y		Biogas refined into traffic fuel
Metener Ltd, Kalmari farm	Leppävesi	Cattle slurry	75 MWh/y electricity, 150 MWh/y heat, 1,000 MWh/y biomethane for traffic fuel.	Microbial fermentation; patented biogas upgrading technology	Biogas
Sybima Ltd	Uusikaupunki			Sybimar's closed circulation concept	Biogas

1.6.4 Iceland, highlights

Icelandic biotech research has so far mostly been within research institutes, and a receptive industrial environment has been lacking. This is changing fast and relatively recent collaborative efforts of research institutes and industry have resulted in a number of new processes and commercialized products. Education and research infrastructure is already at a high level and abundant underexploited bioresources and unique genetic resources are present in the country. However, Iceland lacks complete open-access biorefinery test centers covering production from raw feedstock to product. R&D activities, some of which can be traced back to the early pioneering stages in the 1980s and 1990s, have generated results suggesting the direction with the most promising potential. This will be used as guidance for future development.

An integrated biorefinery can be defined as a biobased production platform that encompases the whole technological chain for processing raw biomass to highly processed value added products. The biorefinery is capable of processing multiple feedstocks, deploys a range of technologies including mechanical, physicochemical and enzymatic preprocessing and fractionation techniques, and further chemical, enzymatic or microbial conversion refinery techniques for product generation. Such a platform aims at complete utilization of the biomass feedstocks, and products for various markets can be taken out at different steps of the process in different volumes and of different values. There is usually a range of product streams such as feed and food components, platform chemicals, speciality chemicals and different energy carriers (biofuels), depending on a value cascade of possible products from the bioresource being processed. Waste materials are used in biogas production or as a fertilizer. There are no complete integrated biorefinery platforms in Iceland, but they exist in part and have some unique local features.

Continoues supply of feedstock is necessary in order to run an efficient commercial biorefinery plant. Therefore alternative bioresources as substitute for fish biomass (if unavailable) are being investigated. The biorefinery platforms being established or considered in Iceland are necessarily based on biomass availability, and most would be considered blue biotechnology based. However, development is also influenced by access to abundant and relatively low-priced energy, such as for the microalgae platform. Potential biorefinery platforms considered important in an Icelandic context and classified by the rainbow scheme of biotechnology include the following:

The classification is based on the source of biomass:

- Fish industry rest raw material biorefinery platform, (waste) Blue Biotechnology.
- The macroalgal biorefinery platform, Blue Biotechnology.
- The microalgae biorefinery platforms, Blue/Yellow Biotechnology.
- Crop plant platform, Green Biotechnology.
- Waste materials biorefinery platform, Green/Blue/Grey Biotechnology.

Status and prospects

International funding received through EU and Nordic collaboration has been of primary importance for developments in the bioeconomy field in recent years. Funding by the national funding bodies AVS (a special fund for the Fish industry in Iceland) and the Technical Development Fund, has been an important factor in initiating this development, launching new projects and securing the necessary interaction between research institutes and industry. Often such projects are expanded to international projects leading to larger scale advances in the bioeconomy.

The AVS fund has proven its worth. A similar fund for establishing and advancing the biorefinery industry in Iceland would be of enormous value for increasing resource efficiency, leading to more complete utilization of bioresources and promoting the bioeconomy in rural and coastal regions of the country.

The status and prospects for biorefinery utilization is different for the different potential bioresource feedstocks. Currently, there is a surge in research activities and subsequent industrialization in fish factory related blue biotechnology that aims at complete exploitation of resources especially in utilization of rest raw materials. The fish industry is also becoming more responsive to biotechnological process solutions than was the case only a decade ago and investment in fish processing biotech is growing fast.

The macroalgae platform is very much less advanced on an industrial basis than the fish industry biorefinery platform. One company in Iceland specializes in harvesting and processing seaweed in bulk. It produces dry milled seaweed, and uses geothermal heat in the drying process. Almost the entire product is exported for further processing by the mother company. A small number of companies in Iceland utilize biological components of seaweed biomass in consumer products targeted at food, food supplement and cosmetic markets.

Table 4: Publicly available biorefinery infrastructures, Iceland

Biorefinery	Location	Biomass Used	Biorefinery Methodology
Matis	Reykjavik with research stations around the country	Various	Biorefinery processes; mechanical, physicochemical and biological. Bioprospecting, biorefinery enzymes; biomolecules; Metabolic engineering of biorefinery organisms. Food and biomass processing
Biotechnology centre in Saudarkrokur (Matis)	Saudarkrokur; North of Iceland	Marine bioresources	Marine biotechnology and pilot processing of rest raw materials from fisheries

The main drivers for the Bioeconomy in Iceland

The main driver for development is the potential for obtaining low priced and environmentally benign energy in Iceland for utilization in biorefineries, in various cultivation processes, preprocessing, dehydration, and fractionation and in subsequent bioconversions of underutilized bioresources to added value products. The proximity to the technologically advanced fish industry is an advantage, as are emerging incentives in this industry for increasing resource efficiency. Further posibilites are in recycling of wastes from aquaculture, establishment of energy efficient (low cost) greenhouses for molecular farming and advancing macro-algal exploitation. The availability of abundant cheap geothermal hot water and carbon dioxide from geothermal power plants are additional supportive factors. A number of industrial initiatives are ongoing, and this is of interest to rural municipalities and companies in aquaculture as an opportunity to recycle waste and produce feed. This is an industry-led development, though still at an early phase. Establishment of a complete open access biorefinery test center could have a significant impact on the development in the biorefinery sector in Iceland.

1.6.5 *Faroe Islands, highlights*

Infrastructure relevant for biorefinery technologies in the Faroe Island The Faroese economy rests heavily on primary production and the biotech sector on the Faroe Islands has mostly been limited to quality control of the production industry.

The recent opening of the Research Park iNOVA, which is equipped with modern equipment such as RT-PCR, Next Generation gene sequencers and mass spectrometry, provides affordable, rent-based access to biotech infrastructure for start-up companies or foreign companies wanting to establish themselves on the Faroe Islands. The first companies to take advantage of the new opportunities are P/F Fiskaaling, which used iNOVA equipment to develop a genetic sex determination test for smolt (juvenile salmon), and Amplexa Genetics A/S, a Faroese owned contract laboratory located in Odense, Denmark, which will conduct genetic tests for the National Hospital of the Faroe Islands.

Table 5: Publicly available biorefinery infrastructures, Faroe Islands

Platform type	Biorefinery	Location	Biomass used	R&D/Refinery methodology	Product(s)
Support					
	Amplexa Genetics	Tórshavn	DNA/RNA	Next gen sequencing and RT-PCR	Researching better fish stock control
	Fiskaaling	Hvalvík	Salmon	Various	Research and development in aquaculture
	Heilsufrøðiliga Starvsstovan	Tórshavn	Various	Various	Quality control of Food and Veterinary products
	iNOVA	Tórshavn	Various	Various	Product development from various bioresources. Tools for biorefineries: Genetics and enzymes / biorefinery organisms
	University of the Faroe Islands	Tórshavn	Various	Various	Research groups focused on the blue bioeconomy, e.g. focusing on peptides in fish slime
Blue biotechnology: Rest raw materials from fish industry					
	Faroe Marine Products	Leirvík	Fish heads and backs	Fermentation	Fermented fish products for human consumption
	Havsbrún	Fuglafjørður	Fish rest materials	Physicochemical refining	Fish feed for aquaculture and fish oil
Macroalgae					
	Ocean Rainforest	Kaldbak	Macroalgae		Macroalgae for human consumption and biochemical industry

The Blue Bioeconomy in Faroe Islands

Fisheries and aquaculture are the two most important contributors to the Faroese economy, contributing over 91% of the total exports in 2012 (Statistics Faroe Islands, 2014).

Marine bioresources are therefore the most important biological resources on the Faroe Islands. Investment in research, innovation and technology along with strengthening the fish stocks is needed to have a positive impact on value creation in the West Nordic countries.

Replace with: As Denmark leads the Nordic council of ministers in 2015, a three year chairmanship program (2015–2017) has been put forward. One important component of the program is the blue bioeconomy program led by the Faroe Islands, focusing on the West Nordic region. The project will focus on four main themes: pelagic fish, white fish, algae and aquaculture (http://www.norden2015.fo/english-edition/the-faroese-charimanship-programme/**)**

Biorefinery development

Biorefinery opportunities lie in fish rest materials feedstock from the fish industry and in offshore seaweed cultivation and subsequent processing. Existing industries are Faroe Marine Products, which produce fermented fish heads and backs for human consumption (exported to Nigerian markets), and Havbrún, which uses raw rest products from the fishing industry to produce fish feed for aquaculture and fish oil.

Research infrastructure is being established at the well-equipped and spacious research facilities of iNova (http://www.inova.fo/) in Tórshavn. Expertise is accumulating and collaboration with various Nordic and other international groups has started. There are possibilities for collaboration within the West Nordic region where similar interests and bioresources are found, especially in blue biotechnology, in bioprospecting of marine organisms, microbes, algae and invertebrates, in seaweed utilization and for complete fish harvests. Ambitious and highly advanced development is in progress on the Faroe Islands in offshore cultivation and the subsequent utilization of seaweed by Ocean Rainforest (http://oceanrainforest.com/).

1.6.6 *Greenland, highlights*

Potential and infrastructures of relevance for the Bioeconomy in Greenland

Possibilities of fish farming are being considered along with cultivating macro algae. Trout and mussels have been cultivated earlier with little success.

Private companies have applied for permission to collect seaweed for test collection in order to start commercial production in the near future. Arctic seaweed production is a unique opportunity that can be developed in Greenland as a supplement for commercial fisheries and hunting and also as local cuisine in restaurants.

The fishing Industry has research in progress on production of fish oil and fish meal and intends to continue developing this process.

Businesses that use biotechnology to transform biomass have not yet developed in Greenland. Even so, the prospect for future development and identification of opportunities in this field in Greenland can be good because Greenland is rich in bioresources. Today the bioeconomy plays a major role in Greenland's economy. Fishing is by far the most important export sector in Greenland's economy. Fishery exports amount to 91% of merchandise exports (Ögmundsson 2014).

In Greenland the Arctic Technology Centre (ARTEK) educates engineers and carries out research and innovation projects in Arctic technology. The centre and its activities are anchored both in Greenland and in Denmark. The centre is a collaboration between Teknikimik Ilinniarfik, KTI (Tech College Greenland) in Sisimiut and the Technical University of Denmark (DTU) in Lyngby, and organisationally is part of the department of Civil Engineering (DTU BYG). The activities take place in close collaboration with Greenlandic communities, local Greenlandic authorities and industries. The Constructions and Physical Environment department at ARTEK is an interdisciplinary group, focusing on research and education in cold climate science and engineering related to constructions and transportation infrastructure in the cryosphere (snow, ice, permafrost) and arctic marine environment. The department seeks innovative approaches to solve research problems and adapt conventional technologies to cope with the cold climate. This contribues to the stronger infrastructure and increased innovation capacity necessary when furthering the economy through use of natural resources, including bioresources.

Food processing is also being developed by small private companies, some with rather good success through sales in shops in the larger towns. This area also has great potential for development.

Inuili is a modern technical school that educates staff in all food-related industries and employment. Iniuli is also a resource centre that collects and analyses data, and disseminates knowledge to promote food and food-related issues with a special focus on more and better use of ingredients from Greenland.

Greenlandic agriculture and the Agricultural Consulting Services aim to support Greenland's agricultural development. The Upernaviarsuk experimental farm is the Greenlandic Government's research and training centre for the agricultural sector. Within the area of plant cultivation, research is conducted with various perennial grasses for the production of hay and silage, amd there are experiments with annual feed crops such as grains, primarily rye, barley and oats, as well as ryegrass and varieties of the cabbage family. There is a small agricultural school at Upernaviarsuk.

When looking towards the future at possible biotech businesses in Greenland, there are many challenges that will not be mentioned here. However, the issue of transport needs to be addressed. Overland transport in Greenland is almost solely within each community/settlement, because the infrastructure (roads and trails) is extremely limited. This is primarily due to the Arctic weather conditions and the vast distances between towns. This is a great challenge when it comes to the use of raw fish rest materials from the fishing industry.

The Government of Greenland supports sustainable use of all living resources including marine mammals, based on sound biological advice, but international obligations and restrictions restrict or forbid commercial use and trade. There is a potential in products such as proteins and oils from certain seal species. Other marine mammals are subject to CITES rules and there is no export or commercial use of them.

Greenland has no research institute focusing on increasing value and development of the economy from bioresources. The establishment of such a research and development institute/company could be highly beneficial for Greenland for the development of biotechnological possibilities and innovation in the bioeconomy. A focus on research and innovation in this field in Greenland could result in added value through a more developed value chain from bioresources.

1.6.7 Sweden, highlights

Biorefineries

Sweden is in the forefront of implementing biofuels for transportation, and a considerable amount of infrastructure is developed to commercialize transportation fuels. Apart from the biofuels (mainly bioethanol, biogas and RME) the product range from the Biorefineries include a variety of chemicals (including platform chemicals, speciality chemicals, pharmaceuticals and fertilizers and minerals for soil improvement), and Food and Feed additives (animal feed and food ingredients and nutraceuticals).

Strategies

Sweden has a national research and innovation strategy, formulated by the Swedish Research Council Formas (http://www.formas.se/Forskning/Formas-Publikationer/Swedish-Research-and-Innovation-Strategy-for-a-Bio-based-Economy/). A national bioeconomy strategy is on its way (JCR, SCAR, 2014).

The bioeconomy is defined as an economy based on:

- A sustainable production of biomass to enable increased use within a number of different sectors of society. The objective is to reduce climate effects and the use of fossil-based raw materials.
- An increased added value for biomass materials, concomitant with a reduction in energy consumption and recovery of nutrients and energy as additional end products. The objective is to optimize the value and contribution of ecosystem services to the economy.

The highest ranked drivers include:

- Contribution/implementation of the EU strategy on bioeconomy.
- Independence from fossil resources/security of supply.
- Development of new bioeconomy sectors (bioenergy, industrial biobased products).
- New business, increased employment.
- Mitigation of climate change/adaptation to climate change.
- Resource efficient economy (reduction of waste, use of residues).

Industry sectors

The established industrial sectors targeted as candidates interested in biorefining technologies and biorefineries include the chemical industry, agricultural industry and forestry industry. The chemical industry has an interest to change from fossil raw materials to biomass. The forestry industry and agricultural industry are both established users of biomass as raw materials, but with an interest in complementing their product portfolio and increasing utilization of the raw material side streams. Upstart companies and SMEs are actors that continue to boost development, and networks between small and larger companies are often created via interest organizations (e.g. skogsindustrierna, and innovation and kemiindustrierna) that create clusters, which can be influential bodies for contacts with stakeholders and funding agencies.

Biomass

The main biomass resources in Sweden today come from forests (23.2 million ha is productive forest land, with a productivity of approximately 0.4 tonnes dryweight/ha, year) and agricultural lands (397 thousand ha, with productivity of 10–30 tonnes dryweight /ha, year). But *marine resources* (including fisheries, microalgae and macroalgae) are poorly utilized, and despite the potential high productivity of macroalgae (10–70 tonnes dryweight /ha, year), these today instead pose an economic burden for coastal communities (macroalgae are transported away from harbours and beaches).

Publicly funded open access facilities

The biorefining research field has attracted increasing interest during the last 10-year period. Access to test facilitie*s* for pilot trials in different scales is important for closing the gap between lab-scale production of novel model reaction and products. Test facilities are often supplied by academic research organizations and research institutes, which are highly relevant actors for the implementation of the bioeconomy. During the development stages equipment for development of technologies is of special interest via actors with open access facilities. A few of these facilities are available and examples are shown in the Table 6.

Table 6: Publicly available biorefinery infrastructures, Sweden

Organisation	Location	Biomass used	Description/Methodology	Products
SP	www.sp.se *Borås* *Lund* *Göteborg* (Anneli Petersson, Sune Wännström) *Örnsköldsvik* Pilot plant location *Södertälje*: facility for biomass valorization and product development.	Any	SP Technical Research Institute of Sweden is an international research institute working in all parts of the innovation chain Has since 2013 the operational responsibility for a biorefinery demonstration plant in m^3-scale (see also home page of SEKAB) in Örnsköldsvik	Any metabolites or hydrolysates
SP Processum AB	www.processum.se *Örnsköldsvik* (Björn Alriksson)	Any	Research institute unit with research related to biorefinery applications. Equipment for fermentation in lab and 50 L scale. Extraction and Steam explosion equipment.	Any metabolites or hydrolysates
KTH / Biopro-duce	www.bioproduce.se *Stockholm* (Andres Veide)	Formats for fermentors	SME located at Albanova (KTH) focusing on contract production of enzymes and microorganisms by fermentation. Facilities for up to 700L scale	Microorganisms or metabolites
LTH (Lund Uni-versity)/ Chem. eng. (PDU)	http://www.chemeng.lth.se/pdu/ Lund (Mats Galbe)	Any	The Process Development Unit (PDU) has a long and succesful tradition within the lignocellu-lose-to-bioethanol, but also in biorefinery applications. Open access pretreatment, hydrolysis, and fermentation of biomass to ethanol. (Scale is typically 2–20 kg dry matter, fermentation <100L)	Any hydrolysates, microorganism (suitable for STR-fermentation) or metabolite
Max IV	https://www.maxlab.lu.se/sv/maxiv *Lund* (Marjolein Thunissen)	Purified components	Crystallization and synchrotron facility	Structure determination of novel proteins, materials etc.
SciLifeLab	http://www.scilifelab.se *From 2015 extended to include labs in Stockholm, Uppsala, Lund Linkoping and Umeå (see web-page for details)*	Any	Laboratories equipped for life science related analyses	Proteomics, bioin-formatics, genomics, diagnostics etc.

Bioeconomy relevant research and innovation

Sweden has a long and successful research history in the field of biomass conversion, with research spread among many academic institutions with slightly different research profiles. The universities most frequently mentioned in collaborations with industry are Lund University (LU), Royal Institute of Technology (KTH) and Chalmers University of Technology.

Innovations and development close to the applications is driven for example by the research institute Innventia, which has a close connection to the forest industry. The Swedish Technical Research Institute (SP) has also initiated major efforts in the field, for eample SP has taken over 60% of the Processum research cluster.

Recently, the large strategic innovation area "Bioinnovation" was also started (see home page at www.bioinnovation.se for participating organizations) after evaluation of research agendas selected via a call from the funding agency Vinnova. This has resulted in major funding in the innovation sector related to biomass conversions (with the main focus on forest biomass). Among the many research clusters in the field, one successful example is Bio4Energy (see www.Bio4Energy.se for a list of members), focusing on biomass conversion via gasification and biorefining.

Several funding agencies support research in the field. Examples are initiatives from Formas, which has a current focus on biomass utilization, and issues calls ranging from primary production to more processing related calls.

1.6.8 Denmark, highlights

The status of Bioeconomy in Denmark

The Danish Government has appointed a National Bioeconomy Panel, consisting of members from leading companies, researchers, and organizations, including representatives from in all five Danish ministries (http://agrifish.dk/fileadmin/user_upload/NaturErhverv/Filer/Tvaergaaende/Biooekonomi/Fact-sheet_The-National-Bioeconomy-Panel.pdf). The objective of the National Bioeconomy Panel is to help identify ways to procure cheap and sustainable biomass to substitute for fossil resources, to identify focus areas for technology development, and to ensure that Denmark will benefit from the European Structural funds for investment to make the production of sustainable biomass economically feasible (http://fvm.dk/nyheder/nyhed/nyhed/regeringen-samler-kraefterne-om-biooekonomien/).

The National Bioeconomy Panel has identified a number of value chains, some of which have already been implemented, and some that are at a very early stage and will need further development (Table 7.).

Table 7: Possible promising value chains as identified by the National Bioeconomy Panel

Biomass	New value chain	Existing use
Blue Biomass: Fish discard and fish waste	Food ingredients, protein rich feed, fish oil for human consumption	Low value animal feed, biogas
Blue Biomass: Macro Algae	Cosmetics, food ingredients, food, health products, polymers	Is only sporadically used
Green Biomass: Grass, Clover and other plants and plant parts	Extraction of protein (for animal feed) and possibly also high value produce (such as vitamins, food ingredients), utilization of waste rich in fibers	Rough feed, biogas or fertiliser for organic crop cultivation
Green Biomass: Alternative protein crops	Protein for, for instance, animal feed from alternative protein crops, such as clover, grass and broad beans	Animal feed
Yellow Biomass: Straw, other cellulosic by-products	Biorefining, conversion into sugars and lignin, which can be used as raw materials for production of second generation biofuels and biomaterials	Combustion, deep bedding, ploughing-in
Brown Biomass: Wood	Production of gas, possibly including upgrading of gas to natural gas through gasification of wood in local plants	The biomass is not produced to its full extent Burning of wood chips
Waste from meat production	Upgrading of meat protein and energy resource	Meat and bone meal, animal feed
Waste from dairy	Whey protein used for various food products	Some of the whey is

Biomass	New value chain	Existing use
Unsorted household refuse	Biogas and new materials from household refuse: through the "REnescience" process, a bioliquid is made, which may be used for microbial production of materials or biogas	Direct burning
Protein-rich animal feed	Improved livestock feed/protein absorption by enhancing bioaccessibility and specificity of, for instance, protein in the feed	Animal feed

Source: Modified from: http://naturerhverv.dk/fileadmin/user_upload/NaturErhverv/Filer/Tvaergaaende/Biooekonomi/Udtalelse_sept2014_Bilag1.pdf

Table 8: Publicly available biorefinery infrastructures, Denmark

Biorefinery	Location	Biomass in focus	Biorefinery, methodology	Product(s) in focus
Aalborg University	Aalborg /Copenhagen		Continuous Hydrothermal Liquifaction (HTL) pilot plant for multiple organic input streams (eg lignocellulosics, grasses, organic residual streams)	Liquid biofuels, refinery bio-intermediates, petrochemical bio-equivalents, fuels from CO2
Aarhus University	Foulum	Lignocellulose	Hydrothermal conversion pilot plant (HTL) – continuous with energy recovery	Bio- crude oil and biobased chemicals (bioenergy)
Aarhus University	Foulum	Perennial grasses and other green biomass	Green biorefinery for production of protein enriched animal feed from green clover/grass	Animal feed
Aarhus University	Foulum		Biogas pilot plant including biogas to SNG upgrading	Bioenergy, energy storage
Aarhus University	Aarhus		Lipid extraction and conversion	Functional lipids and fuels
Agrotech	Aarhus		Assistance in prototype development and proof of concept. Harvest techniques and storage trials	
Amager Resouce Center (ARC)	Copenhagen	Household waste	Facilities for collaborative development of new ways of upgrading organic waste streams	Bioenergy, construction materials, Recycling of plastics and metals
University of Copenhagen	Copenhagen	Lignocellulosic biomass	High throughput pretreatment and enzymatic hydrolysis systems (HTPH-systems) for screening of lignocellulosic biomass for enzymatic saccharification.	Sugar platform, Bioenergy

Biorefinery	Location	Biomass in focus	Biorefinery, methodology	Product(s) in focus
University of Copenhagen	Copenhagen	Green biomass	High throughput amino acid analysis based on microwave assisted protein acid hydrolysis for screening of protein quality	Protein platform, proteomics, genomic selection
Dong Energy Inbicon Biorefinery (Temporarily closed)	Kalundborg	Wheat straw	2nd generation Bioethanol plant pilot plant	Bioenergy
Danish Technological Institute (DTI)	Taastrup/Aarhus		Up-scaling facilities for pretreatment, storage stability and biomass conversion product development	Bioenegy, biochemical, biomaterials, food and feed ingredients
Technical University of Denmark (DTU) Center for Bioprocess Engineering (BIO-ENG)	Kgs. Lyngby		Pretreatment pilot plant; Upscaled fermentation bioreactors	
Technical University of Denmark (DTU) Center for Bioprocess Engineering (BIO-ENG)	Kgs. Lyngby		GMO Fermentation Pilot Plant	
European Protein, Aarhus University and pig farmer Henrik Mols	Jelling	Rape, Sunflower, favabean	Demonstration plant	Fermented protein feed
MEC Maabjerg Energy Concept	Maabjerg	Wheat straw and household waste	Full scale 2nd generation Bioethanol plant	2nd generation bioethanol and other bioenergy products.
N.C. Miljø	Nyborg	Biowaste	Full-scale plant Supermarket waste is the main input today, but SDU is running experiments with household waste	Bioenergy (biopulp for biogas)
Roskilde University	Roskilde	Lignocellulosic biomass	Calorimetric equipment platform	Enzyme cocktails for deconstruction of agricultural residue
University of Southern Denmark (SDU)	Odense	Lignocellulosic and waste biomass	Yellow and Green Biorefinery Biogas pilot plant	Bioenergy

Biorefinery	Location	Biomass in focus	Biorefinery, methodology	Product(s) in focus
University of Southern Denmark (SDU)	Odense		Reactive crystallization for phosphorus recovery	phosphorus
University of Southern Denmark (SDU)	Odense		Crystallization for natural products isolation and purification	Natural products with pharmaceutical activity
University of Southern Denmark (SDU)	Odense	Vegetable oils and fats. Straw degradation	Biodiesel and second generation bioethanol production Process simulation of biofuel refineries	Biofuels
University of Southern Denmark (SDU)	Odense	Usage of waste from the fishery industry	Protein and pigment re-covery from fish and shrimp waste streams. Extensive experience with membrane processes for product separation	Food additives
University of Southern Denmark (SDU)	Odense	Extraction and purification of secondary me-tabolites from algae and plants	Extensive experience with extraction and separation processes for product separation of secondary metabolites like pigments, flavonoids, aromas, poly-saccharides etc.	Natural food additives and l health products
University of Southern Denmark (SDU)	Odense	Separation of animal manure	Extensive experience with membrane processes for separation of fertilizer fractions from animal slurry	Liquid and solid fertlizers
Unibio A/S Danish Technical University (DTU)	Odense Kgs. Lyngby		Large-scale demonstration plant Production of protein from *M.capsulatus* with me-thane (and a nitrogen source) as the main input	Protein for animal feed

Major bioeconomy and biorefinery relevant research and innovation projects

- INBICON: http://www.inbicon.com/en & REnescience.
  – http://www.renescience.com/en
- BioBase – a research initiative of the University of Aarhus with four research platforms (Green biomass, green protein, HTL, Societal, environmental, ecological and economic assessments.
  – http://dca.au.dk/forskning/bioraf/forskningsinitiativer/biobase/
- Maabjerg Energy Concept: The Maabjerg Energy Concept envisions creating a comprehensive, sustainable energy solution, based on

local and CO2-neutral raw materials, by using the latest technologies. The project merges several energy supply objectives (CHP, Biogas, Bioethanol) in a holistic system concept, where the synergy between the individual solutions is used optimally and with great effectiveness, through the utilisation and alignment of energy streams between the individual plants.
– http://www.maabjergenergyconcept.eu/

- Biomass for the 21st century: Integrated biorefining technologies for shipping fuels and biobased chemicals (B21st). A platform which brings together leading players within the sustainable use of biomass. The platform provides a framework for the parties' joint research aimed at developing specific sustainable solutions for the production of building blocks for chemicals and biobased fuels for the global shipping industry.
– http://news.ku.dk/all_news/2011/2010.12/new-research-platform-paves-way-for-future-bio-based-society/ ; http://b21st.ku.dk/
- BioValue SPIR: The aim of the BIO-VALUE platform is to make sustainable solutions for biorefining technologies. BIO-VALUE deals with entire value chains from sustainable biomass production, to the separation and conversion into new products. The BIO-VALUE platform has a budget of DKK 160 million to develop new sustainable technologies for upgrading plant material into internationally competitive products. Until 2018, the BIO-VALUE platform will strive to provide leading examples on how to kickstart the biobased economy with sustainable high value products, such as proteins, polymers, and chemical components for industry. The platform is funded under the SPIR initiative by The Danish Council for Strategic Research and The Danish Council for Technology and Innovation.
– http://ufm.dk/en/research-and-innovation/funding-programmes-for-research-and-innovation/who-has-received-funding/spir-grant-2012-within-the-bio-based-society-bio-value , http://strategiskforskning.dk/ , http://biovalue.dk/
- OrganoFinery: Organic growth with biorefined organic protein feed, fertilizer and energy, http://icrof.eu/Pages/Research/ORG_RDD2_OrganoFinery.html)
The project is developing a new platform for organic growth based on a concept for biorefinery of green herbage to protein feed, fertilizer and energy. The project will deliver solutions to the following key challenges to the organic sector: supply of organic protein feed to monogastric livestock; improved, climate-friendly,

and robust crop rotations in areas of low livestock density; better use, efficiency of nutrients; and higher yields.

Project activities: Identification of the best suited material for biorefinery through cropping trials; Harvest and extraction of green leaf protein through fermentation; Separation; Production, profiling and testing of organic protein feed on poultry; Treatment of the residual biomass in a biogas plant for the production of biogas and valuable organic fertilizer; Business model development for organic protein feed, fibre material for biogas and for system export; Optimization of the system for upscaling; National and International dissemination:

- BioPro http://www.biopro.nu/ BIOPRO is a Biotech cluster located on Zealand, based on a three-pronged partnership: industry, universities and a fertile regional business environment
- Future Cropping.
  – http://www.biopress.dk/PDF/innovationsfonden-investerer-50-millioner-kroner-i-fremtidens-landbrug

2. Expanded version of Nordic Bioeconomy and mapping of infrastructures

2.1 Bioeconomy in Norway

Alexander Wentzel, SINTEF, Norway and Marit Valseth, Innovation Norway

2.1.1 Bioresources in Norway

The bioresources of major importance in Norway as feedstock for current and future biorefineries are:

- Forest-based biomass and forestry residues (approximately 25 million m^3 biomass increase annually). Top ten species include spruce, pine, birch, alder, rowan, aspen, willow, oak, hazel and prunus.
- Marine byproducts and rest raw materials from fisheries, aquaculture, fish processing (870,000 tonnes processed annually).
- Seaweed/macroalgae (170,000 tonnes wet weight harvested and processed annually; cultivation technology under development, aiming at 2.5 million tonnes in 2050).
- Agricultural crop residues and agroindustrial waste.
- Wet organic industrial residues/sludge (slaughter house, paper, brewing, milling, textile, etc.).
- Organic household waste, municipal solid waste.

Forest-based biomass contributes by far largest share (annual increase approximately 25 million m^3, of which the logging potential is estimated to be 18 million m^3/year over the coming 30 year period). Forest biomass can be divided into saw timber, pulp wood, energy wood, logging wastes, and wood processing industry wastes, of which the different fractions are suitable for different purposes. The costs of the various fractions also differ significantly. Marine biomass and byproducts from the fish and aquaculture industries are also significant in volume and play an important role in Norwegian biorefining. Developments in seaweed cultivation technology may lead to a significant increase in availability of this biomass resource for future biorefineries. Annual plants, agricultural wastes, wet organic residues from different industries and municipal and household organic waste also represent green bioresources, but are available in significantly lower amounts than forest-based biomass. Table 9 summarizes the range of biomass potential in Norway for biorefining and bioenergy purposes. For a comparison with other Scandinavian countries, see the complete Table in Scarlat *et al.* 2011.

Table 9: Estimates of range of terrestrial biomass potential in Norway [PJ]

	Norway
Forest sector	88–124
Wood residues	37–84
Logging residues	14–30
Firewood	37–84
Agriculture	9–19.8
Agri-residues	9–16
Energy crops	3.5–11
Waste	11.9
Industrial waste	2.9
Municipal waste	9
Biogas	8–15
Range of biomass potential	104–167

Source: Modified from: Scarlat *et al.*, 2011.

While land-based biomass is well established as an important source of bioenergy in Norway, marine biomass and residues are currently less relevant for energy production (except for biogas production from marine wastes). However, marine resources are very well established as a source of diverse (including high value) products for other markets, including food&feed supplements, nutraceuticals, cosmetics, etc., in a biorefinery setting.

2.1.2 Infrastructures of relevance for biorefinery technologies and bioeconomy business in Norway

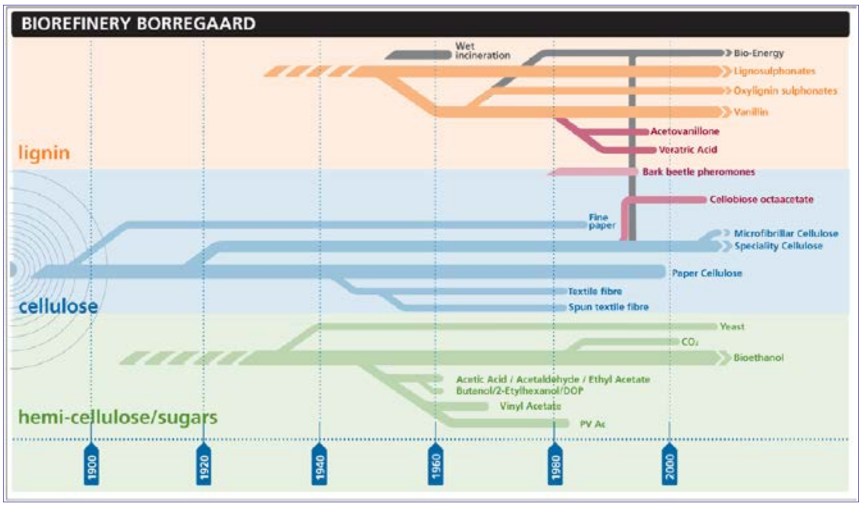
Diverse infrastructures for biorefinery technologies and bioeconomy business exist in Norway, both at public and private research organizations, as well as companies involved in this field. This chapter outlines the most important commercial biorefinery and bioeconomy companies in Norway with their respective technologies and product range, as well as publicly financed key central infrastructures for biorefinery R&D. For specific details about research infrastructure and competence at public and private research institutions in Norway, see section 2.1.3.

A. Commercial biorefineries and bioeconomy companies in Norway

Table 10 lists bioeconomy companies in Norway producing and commercializing products based on bioresources given in chapter 2.1.1. Several large companies like FMC Biopolymer AS (part of FMC Health and Nutrition, making alginates and other high value products from natural seaweed along the Norwegian coast), Cambi AS (technology supplier; diverse biosolids and biowaste to biogass and fertilizer products by anaerobic digestion and thermal hydrolysis) and Norske Skog ASA (wood to paper and byproducts) perform biorefining and commercialize biomass-derived products at significant scales. However, the most significant player in integrated commercial biorefining in Norway is Borregaard AS.

Borregaard operates one of the world's most advanced and sustainable biorefineries in Sarpsborg, Norway. In integrated processes, lignocellulosic biomass from wood and agricultural waste is utilized and converted into multiple products, including speciality cellulose, ethanol (20 million litres/year), vanillin (a world leading supplier), lignin/lignosulfonates (>50% global market share) and bio-energy (Figure 3). Approximately 90% of the incoming lignocellulosic biomass is converted to marketable products (Figure 3).

Figure 3: Historical development of the Borregaard Biorefinery in Sarpsborg, showing production of multiple products from lignocellulosic biomass



Source: http://task39.sites.olt.ubc.ca/files/2013/05/Borregaard-IEA-Vienna-13-14-11-12-GIJO.pdf

Current technological components of the Borregaard biorefinery include (info from: http://www.indbiotech.no/sites/default/files/Gudbrand%20R%C3%B8dserud%20IBNW%2011%20June%2012%20-%20Borregaard.pdf):

- *Sulphite pulping plant*; *chloralkali plant*. Conventional chemical treatment route.
- *BALI™ process* (acid/neutral) for coproduction of sugars and lignin speciality chemicals. Conversion of (almost any) biomass to sugars in solution and soluble lignosulfonates. High purity sugars ready for fermentation to ethanol or chemicals; low level of inhibitors (both for enzymes and yeasts).
- Borregaard BALI™ Demo Plant. 800 m^2 total area; feeds 1 metric tonnes dry matter/day. Fullscale plants are currently being built outside Norway.
- *Lignicellulosic ethanol production plant.* 20 million litres/year by yeast fermentation of monosaccharides (C6/C5 sugars) from spruce hemicellulose.
- *Biological purification plant.* (C5 sugars, wood residues). Biogas by anaerobic digestion for electricity and heat for internal use. (15,500 Nm^3/day biogas, 38 GWh/y, 30 tonnes/day reduction of COD, 27 GWh/year biogas to replace 2,100 tpa propane for spray dryers, reduced CO_2 emissions with 6,300 tonnes/year).
- *Other components*: Mechanical/chemical treatment of lignocellulosic biomass; separation of bark; fibre separation; distillation for ethanol; chemical modification of fibres and lignin, combustion of bark, residues and biogas.

The demonstration plant, called Biorefinery Demo, started preliminary operations in summer 2012, followed by normal operations in the 1st quarter of 2013. The plant relies on Borregaard's proprietary BALI™ technology and is a continuation of today's biorefinery concept. The aim is cost-effective and sustainable production of lignin and bioethanol from new raw materials. BALI™ technology involves converting the cellulose fibres in biomass to sugars that can be used for the production of second generation bioethanol, while other components of the biomass (lignin) become advanced biochemicals.

Table 10: Commercial bioeconomy businesses in Norway with private infrastructure of relevance for biorefinery technologies. Companies with multiple product biorefineries and/or side streams, as well as relevant technologies for further upgrading are in italic

Biorefinery/ Bioeconomy company	Location	Biomass used	Biorefinery/Methodology	Products
Advanced Biopolymers AS (www.advancedbiopolymers.no)	Trondheim	Marine waste	Extraction, isolation, purification	Chitosan-based products for biomedicine and cosmetics, isolated from marine sources. Pharmaceuticals
Agroplas AS (www.agroplas.no)	*Oslo*	*Municipal and industrial waste streams*	*Separation and drying technology, chemical process*	*Improved efficiency of existing production processes and new value streams from waste streams. New products in the food, materials and bioenergy industries*
Aker Biomarine ASA (www.akerbiomarine.com)	*Oslo*	*Plankton / krill*	*Bioprospecting, extraction, isolation, purification, manufacturing*	*Food / feed ingredients. Products and technology, contract manufacturing and analytical services related to modified fatty acids (linoleic acid and omega3) intended for food and feed. Manufacturing plant at Sunnmøre*
Akvaren AS (www.akvaren.no)	*Furuflaten*	*Fisheries and aquaculture waste*	*Biomass collection, storage, processing, pretreatment*	*Collecting and storing fish waste as raw material for marine byproducts, e.g. feed for the aquaculture industry. Production and trading of marine byproducts (oil, fat, flavour, concentrates). Food / feed ingredients*
Algea AS (www.algea.com)	*Kristiansund*	*Seaweed / macroalgae*	*Biorefinery, Biomass pretreatment*	*Cultivation and harvesting of macroalgae for food / feed ingredients, cosmetics, fertilizers and plant growth enhancers*
Algipharma AS (www.algipharma.com)	Sandvika	Microbial biopolymers	Bioprospecting, organic chemistry, fermentation, biocatalysis	Development of new pharmaceuticals based on marine polymers (from alginate polysachharide), focusing on developing medications and therapies in the areas of respiratory diseases (CF & COPD), wound healing and conditions caused by bacterial biofilms
Aqua Bio Technology ASA (www.aquabiotechnology.com)	Bergen	Marine by-products	Bioprospecting, extraction, isolation, purification	Developing and producing cosmetics and skincare products based on active marine ingredients, e.g. the protease zonase from hatching fluids of salmon having skin healing properties. Food / feed ingredients
Arctic Nutrition AS (www.arcticnutrition.no)	Ørsta	Marine by-products	Extraction, isolation, purification	Produces highly refined omega3 phospholipids and protein powder from herring roe
Barentzymes AS (www.barentzymes.com)	Tromsø	Marine resources	Bioprospecting, enzymes / biocatalysis	Discovery, engineering and production of enzymes for industrial applications, e.g. bio-waste
Berg Lipidtech AS (www.blt.no)	Eidsnes	Marine by-products	Extraction, separation, purification	Supply food quality marine oils in bulk for the pharmaceuticals, health food and cosmetics industries
Bio Oil AS (www.bio-oil.no)	*Oslo*	*Lignocellulose*	*Biorefinery, Pyrolysis*	*Bioenergy/biofuels from woody biomass*
Biobag International AS (www.biobag.no)	Askim	Other plant biomass/starch	Organic chemistry, manufacturing	Producing biodegradable plastic films from renewable sources (starch)
Biokraft AS (www.biokraft.no)	*Trondheim*	*Div. industrial waste*	*Anaerobic digestion, biogas production*	*Bioenergy/biofuels. liquid biogas for transportation; Scandinavias largest production plant for liquid biogas*
Biolink Group AS (www.biolink.no)	Sandnes	Other plant biomass	Bioprospecting, organic chemistry, extraction, purification	Pharmaceutical compounds based on anthocyanins and other polyphenols. Food / feed ingredients, pharmaceuticals
Biomega AS (www.marinebio.no)	*Storebø*	*Marine resources and by-products*	*Extraction, separation, purification, enzymes / biocatalysis*	*Oil and bioactive peptides and protein hydrolysate isolated from marine resources; salmon meal, oil, protein/peptides. Food / feed ingredients, speciality chemicals*

Biorefinery/ Bioeconomy company	Location	Biomass used	Biorefinery/Methodology	Products
Bioproduksjon AS (www.bioproduksjon.no)	*Hamar*	*Fat containing wastes*	*Biorefinery, biodiesel pilot plant*	*Bioenergy; biodiesel from fat containing wastes, bio-oil. Production of electricity from biofuels, waste burning and land fill gas*
Biosentrum AS (www.biosentrum.no)	*Stavanger*	*Microbial fermentation substrates*	*Manufacturing service, microbial fermentation up to 30 cubicmeters*	*Contract manufacturing company for large scale fermentation up to 30 cubicmeters; production of fine chemicals, proteins, biopolymers, surfactants, etc.*
Biotec Pharmacon ASA (www.biotec.no)	*Tromsø*	*Marine resources*	*Bioprospecting, vaccines / immunology, enzymes / biocatalysis*	*Discovery and manufacturing of bioactive compounds and enzymes from marine sources. Drug discovery program related to cancer. Pharmaceuticals, food / feed ingredients (includes Arcticzymes AS and BiotecBetaGlucans AS)*
Borregaard Industries Ltd. Norge (www.borregaard.com)	*Sarpsborg*	*Lignocellulose*	*Biorefinery, Chemical process*	*Internationally leading biorefinery for lignocellulose; performance chemicals (LignoTech), specialty cellulose (ChemCell), bioethanol, vanillin, fine and basis chemicals*
Calanus AS (www.calanus.com)	Tromsø	Crustacean / clams	Bioprospecting, extraction, separation, purification	Food/feed ingredients and bioactive reagents/pharmaceuticals from marine plankton (Calanus); Calanus oil (omega-3)
Cambi AS (www.cambi.no)	*Asker*	*Municipal and industrial waste*	*Anaerobic digestion, Thermal hydrolysis*	*Builds and manages processing plants for biosolids and biowaste throughout the world. Uses a thermal hydrolysis technique to produce biogass and nutrients for farming. Bioenergy/biofuel, fertilizer*
Chitinor AS (www.seagarden.no)	*Senjahopen*	*Crustacean / clams, marine waste*	*Biomass pretreatment, extraction, separation, purification*	*Manufacturing of high quality chitin from shrimps for medical and cosmetical use. Chitosan. Food / feed ingredients*
Con Tra AS	Tromsø	Marine resources	Bioprospecting, Enzymes / biocatalysis	Manufactures marine enzymes used in processing of fish derived consumer products
Denomega Nutritional Oils AS (www.denomega.no)	Leknes, Ålesund	Marine resources, marine by-products	Extraction, separation, purification	A leading supplier of taste and odor free marine Omega-3 ingredients for use in Functional Foods and Dietary Supplements; salmon oil, cod liver oil. Food/feed ingredients
Due Miljø AS (www.duemiljoe.no)	Oslo	Diverse	Process development, separation technology	Membrane filtration devices for molecular separation, pharma, food & feed, and process industry
Eco Energy Holding AS (www.eco.as)	*Bergen*	*Fuel oils*	*Chemical process, emulsion technology*	*Water in oil microemulsions to create less polluting fuel. Technology platform, Biofuel*
Eco-Pro AS (www.ecopro.no)	*Værdal*	*Organic waste*	*Anaerobic digestion*	*Bioenergy/biogas, Fertilizers. Biogas plant in Verdal – owned by Statkraft*
Eidsiva Bioenergi AS (www.eidsivaenergi.no)	*Gjøvik*	*Lignocellulose, waste*	*Bioenergy production, incineration*	*Bioenergy for district heating from wood and waste*
Enviro Solution AS (www.envirosolution.no)	*Bjorli*	*Municipal waste*	*Biomass pretreatment by enzymatic hydrolysis.*	*Enzymatic process for hydrolysis of wet organic waste as pretreatment for biogas production. Bioremediation service, biofuel*
Epax Norge AS (www.epax.com)	Ålesund	Fisheries / aquaculture	Biomass pretreatment, organic chemistry, extraction, separation, purification	Food ingredients, Speciality chemicals. Omega-3 ingredients; purification and concentration of fish oil/marine oils
Eximo AS/Trofi (www.trofico.no)	Tromsø	Marine resources	Extraction, separation, purification	Feed ingredients and fine chemicals, e.g. phospholipids and DNA, from marine sources
Firmenich Bjørge Biomarin AS (www.firmenich.com)	Ellingsøy	Marine resources	Bioprospecting, Organic chemistry, extraction, separation, purification	Flavour ingredients and Nutraceuticals extracted from marine sources. Part of the Swiss based company Firmenich. Personal care / cosmetics, speciality chemicals

Biorefinery/ Bioeconomy company	Location	Biomass used	Biorefinery/Methodology	Products
Fmc Biopolymer AS (www.fmcbiopolymer.com)	*Sandvika*	*Seaweed / macroalgae*	*Biorefinery, organic chemistry, extraction, separation, purification, manufacturing*	*Food ingredients, pharmaceuticals. Products based on alginate with main manufacturing plant in Haugesund and Drammen. Two business units within human and veterinary medicine, respectively. Speciality chemicals; alginates, fucoidan (ProtaSea), etc.*
Fortuna Oils AS (www.fortunaoils.no)	Kristiansund	Marine resources	Extraction, separation, purification	Food / feed ingredients. Speciality omega3 oils from seal and salmon
GC Rieber Oils AS, GC Rieber Omega-3 Concentrates AS (http://www.gcrieber-oils.no/)	Kristiansund	Marine resources, marine by-products	Biomass pretreatment, extraction, separation, purification	Supplier of highly concentrated omega-3 lipids from fish and other marine oils
Hepmarin AS (www.hepmarin.no)	Ås	Marine resources	Extraction, separation, purification	Medical quality heparin manufactured from marine sources. Pharmaceuticals
Hofseth Biocare ASA (www.hofsethbiocare.no)	Asker	Marine resources, marine by-products	Extraction, separation, purification, enzymes	Production of food and feed ingredients from marine biomass; Salmon oil, marine calcium, protein; value added marine ingredients for human applications
Hordafor AS (www.hordafor.no)	Bekkjarvik	Fisheries / aquaculture	Biorefinery, extraction, separation, purification. GMP+ facilities	Marine feed ingredients from fish residues; fish oil, marine protein hydrolysates. Food / feed ingredients, Speciality chemicals
Hortimare AS (www.hortimare.com)	*Hardbakke*	*Seaweed / macroalgae*	*Biomass production, Seaweed cultiva-tion technology*	*Cultivation and harvesting of seaweed*
Hyperthermics Holding AS/Energy AS (www.hyperthermics.com)	*Hovdebygda*	*Industrial wastes*	*Microbial fermentation, biocatalysis*	*Proprietary thermophilic microbial strains from deep sea vents. Technology platform, Biogas*
Krüger Kaldnes AS (www.krugerkaldnes.no)	*Sandefjord*	*Wastewater*	*Process development, Microbiology*	*Supplier of technology and products for biologically based wastewater treatment. Applications related to oil&gass industry, aquaculture and medical manufacturing plants. Bioremediation service*
Lindum AS (www.lindum.no)	*Drammen*	*MSW*	*Anaerobic digestion, MSW handling*	*Biogas, waste collection, treatment and disposal; Northern-Europes leading waste company; 6 subsidiaries. Remediation*
Marealis AS (www.marealis.com)	*Tromsø*	*Marine resources, shrimps*	*Bioprospecting, high throughput screening, extraction, separation, purification*	*Discovery and development of marine derived bioactive ingredients for health applications. Owned by Stella Polaris AS. Peptides from Arctic Coldwater shrimps (angiotensin converting enzyme inhibitor). Food / feed ingredients, Pharmaceuticals*
Marine Harvest Ingredients (www.marineharvest.com)	*Hjelmeland*	*Marine resources, marine by-products*	*Extraction, separation, purification*	*Manufacturing of omega-3 fatty acids and other food/feed ingredients. Daughter company of Marine Harvest, a major producer of fish filet and processed fish products for the consumer market*
Maritex AS (www.maritex.com)	Oslo	Marine resources, marine by-products	Extraction, separation, purification, organic chemistry, enzymes	Wholly owned by TINE with R&D and production related to various marine-based chemicals, e.g. fish peptones and fish/marine oils. Food / feed ingredients
Moelven Bioenergi AS (www.moelven.com)	*Moelv*	*Lignocellulose, wood*	*Energy production*	*10 MW power station, steam from woody biomass*
Navamedic ASA (www.navamedic.com)	Lysaker	Marine resources, Crusta-cean / clams	Separation, purification	Develops and markets pharmaceutical product for osteoarthritis (OA) based on glucosamine HCl, a marine biproduct from shrimps. Consumer care, medical nutrition, pharma

Biorefinery/ Bioeconomy company	Location	Biomass used	Biorefinery/Methodology	Products
Norilia AS (www.norilia.no)	Oslo	Livestock / dairy	Biomass pretreatment, process development, manufacturing	Focus on opportunities in by-products from livestock. Hides/skins, casings, wool; processing of value added products from Nortura, Noridane and Norskinn. Research service
Norner AS (www.norner.no)	Stathelle	Petrochemicals, biomass	Process development, Chemical process	Independent industrial polymer institute, Research service, Material testing
Norsk Protein AS (www.norskprotein.no)	*Ingeberg*	*Livestock / dairy*	*Biomass pretreatment and processing*	*Feed, bone meal, animal fat, protein, fertilizer*
Norske Skog Holding AS (www.norskeskog.no)	*Lysaker*	*Lignocellulose, wood*	*Chemical process, pulping, biomass pretreatment, biogas/bioenergy technology, process technology*	*Internationally leading producer of paper, e.g. newsprint and magazines. Whole value chain; byproducts to biogas/bioenergy, chemicals*
Nortura SA (www.nortura.no)	Oslo	Livestock / dairy	Biomass pretreatment, process development, manufacturing	Norway's leading supplier of meat and eggs; cooperative owned by 18,700 Norwegian farmers
Nutrimar AS (www.nutrimar.no)	Kverva	Marine resources, marine by-products	Biorefinery, extraction, separation, purification, organic chemistry	Produces oil and protein extracts from salmon. High quality oil, protein concentrate and meal from salmon. Food / feed ingredients
Olympic Seafood AS/Emerald (www.olympic.no)	Fosnavåg	Marine resources, fish, plankton / krill	Krill harvesting, Biomass pretreatment, extraction, separation, purification	Pioneer in the harvesting and use of krill. Global provider of seafood, specialty ingredients and marine raw materials
Palm Research AS, Lectinect AS (www.lectinect.no)	Bergen	Other plant biomass	Organic chemistry, Extraction, separation, purification	Bioactive lectins with an immunostimmulating effect on the human intestinal system. Food / feed ingredients, Pharmaceuticals
Pharma Marine AS (www.pharmamarine.com)	Søvik	Marine resources, marine by-products	Extraction, separation, purification, enzymes	Producer of omega3 lipics (DHA) from squid and cod. EPA/DHA from fishery byproducts in the Arctic Sea. Food / feed ingredients
Pharmatech AS (www.pharmatech.no)	Rolfsøy	Herbs, other plants	Extraction, separation, purification, manufacturing	More than 250 specialty products.Vitamins, mineral and trace element products, lcithin and oil products, herbal extracts, cosmetics, etc. Food / feed ingredients, Pharmaceuticals
Polarol AS (www.polarol.no)	Drøbak	Marine resources, marine by-products, plants	Extraction, separation, purification, manufacturing	Marine and plant oils and antioxidants. Food / feed ingredients
Primex Biochemicals AS (www.primex.no)	Haugesund	Marine resources, marine by-products	Extraction, separation, purification	Icelandic Primex took over Primex Ingredients in Haugesund i 2001. Focus on chitin products. Food / feed ingredients. Capacity: 500 tons chitosan per year. Now owned by Balder Management
Promar Aqua AS (www.promaraqua.no)	Bodø	Microalgae	Microalgae cultivtion, separation, purification	Manufacturing of astaxanthin to the salmon feed market using a proprietary bioreactor technology
Pronova Biopharma ASA (www.pronova.com)	Lysaker	Marine resources, marine by-products	Separation / purification, Organic chemistry	Dietary supplements, clinical nutrition. Omega-3 fatty acids from marine resources. Pharmaceuticals, Food / feed ingredients
Protia AS (www.protia.no)	*Oslo*	*Natural gas, biogas*	*Organic chemistry*	*Technology platform that converts natural gas/biogas to diesel w/o use of Fischer Tropsch synthesis*
Rosenrot Norge AS (www.nutraingredients.com/smartlead/view/207252/4/Rosenrot)	Skage I Namda-len	Other plant biomass. Rhodiola rosea	Cultivation technology, Extraction, separation, purification	Health food supplements based on Rhodiola rosea

Biorefinery/ Bioeconomy company	**Location**	**Biomass used**	**Biorefinery/Methodology**	**Products**
Scalpro AS	Rong	Diverse, marine resources, marine by-products	Aquaculture technology, manufacturing	Development and production of feed for aquaculture of scallops
Scanbio AS (www.scanbio.com)	*Trondheim*	*Marine by-products*	*Extraction, separation, purification, enzymes*	*Producing protein hydrolysate and oil from fish waste. Protein concentrate and meal, fish and marine oil*
Scandiderma AS (www.scandiderma.com)	Tromsø	Seaweed / macroalgae	Bioprospecting, extraction, separation, purification, manufacturing	Development of topical cream for treatment of psoriasis. Pharamaceuticals, cosmetics
Seagarden ASA (www.seagarden.no)	*Haugesund*	*Marine resources, marine by-products*	*Bioprospecting, extraction, separation, purification, manufacturing*	*Manufactures and sells worldwide bulk extracts and savoury ingredients from marine organisms. Food / feed ingredients*
Seaweed Energy Solution AS (www.seaweedenergysolutions.com)	*Trondheim*	*Seaweed / macroalgae*	*Cultivation, harvesting, biorefinery*	*Cultivation, harvesting and processing of seaweed for biorefining and biofuels*
SENJABIO AS (www.senjabio.no)	*Husøy*	*Diverse biomass, biomass wastes*	*Biorefinery*	*Startup focusing on marine by-products. Utilization of byproducts from producers, use of bioenergy and ecologicalization of agriculture; biorefinery concept*
Silvanus Biofuels AS	*Ulefoss*	*Diverse biomass wastes*	*Anaerobic digestion, biorefinery*	*Production of bioenergy/biogas. Plans for industrial production of synthetic fuels from biomass and hydrogen from electrolysis*
Standard Bio AS (www.standard.bio)	*Oslo*	*Wood, land-based biomass*	*Process development, Biomass pretreatment Biorefinery*	*Innovative biomass dewatering solutions, process innovation and engineering, development of novel bio-based products, food / feed products, fertilizer*
Statoil ASA (www.statoil.com)	Stavanger	Seaweed / macroalgae, wood	Biorefinery, enzymes / biocatalysis	Petroleum company. Projects on the biofuels/biorefinery value chains from marine and land-based biomass; currently no longer prioritized
Stella Polaris (www.stellapolaris.no)	Finnsnes	Prawns/shrimps	Biomass supply, biomass pretreatment	Producer of cold water shrimps
Tine SA (www.tine.no)	*Oslo*	*Livestock / dairy*	*Biomass supply, processing, manufacturing*	*Major farmers cooperative for dairy products*
Treklyngen Holding AS (www.vikenskog.no/default.php?aid=724)	*Hønefoss*	*Woody biomass*	*Biorefinery, Process development*	*Innovation branch of Viken Skog, one of the largest forest owner cooperatives in Norway. Plans to produce advanced bioenergy products; cellulose-based feedstock. Bioenergy/biofuels*
Umoe Bioenergi ASA (www.umoebioenergy.com)	Lysaker	Agriculture, 1st gen. biomass	Biomass preprocessing, microbial fermentation	Bioenergy/biofuels. Bioethanol from sugar cane in Brasil
Vedde AS (www.vedde.no)	Langevåg	Marine resources, fish, marine by-products	Biomass preprocessing, separation, purification	Well established producer of fish meal and fish oil as feed ingredients (herring)
Vital Seafood AS (http://foretak.io.no/992336757)	Stranda	Marine resources, marine by-products	Extraction, separation, purification	Producing fish oil from aquaculture. Food / feed ingredients
Weyland AS (www.weyland.no)	*Rådal*	*Lignocellulose*	*Biomass pretreatment, Chemical process, Fermentation. Pilot plant 200 cubicmeters per year*	*Acid hydrolosys of cellulose material as pretreatment for microbial bioethanol production by fermentation*

Biorefinery/ Bioeconomy company	Location	Biomass used	Biorefinery/Methodology	Products
Zeg-Power AS (www.zegpower.no)	*Kjeller*	*Biogas*	*Technology development, Fuel cells*	*Biofuels, electrical power and hydrogen from hydrocarbon gases with integrated CO2 capture. Hydrogen from biogas*
Zymtech Production AS (www.zymtech.no)	Lesja	Marine resources, fish, marine by-products	Biomass pretreatment, enzymatic hydrolysis, separation purification	Food / feed ingredients. Large scale production of protein hydrolysate and amino acids from fish protein (salmon), intended initially for health food

B. Publicly financed biorefinery infrastructures in Norway

Important publically financed national centres and infrastructures for biorefinery technologies and the bioeconomy are the Norwegian Centre for Bioenergy Research in Ås, the Norwegian Biorefinery Laboratory NorBioLab in Trondheim and Ås, and the National Facility for Marine Bioprocessing NAMAB in Tromsø. Equipment at these centres is publically available within the frame of research projects in collaboration with the participating institutions.

Table 11: Publicly financed biorefinery infrastructures in Norway

Central Biorefinery infrastructure (Hosts)	Location	Biomass used	Biorefinery/Methodology	Products/ Research areas
Norwegian Centre for Bioenergy Research (NMBU, Bioforsk, Skog og Landskap)	Ås	Lignocellulosics from forestry and agriculture; industrial and municipal waste	Steam explosion unit. 20 L reactor. National biogas facility. Advanced analytical laboratory. NMBU Biorefinery laboratory. Pilot scale laboratory for biomass processing. Milling, hydrolysis (up to 100 L reactors), separation equipment, spray drying. Enzyme production and application facility. Fermentation equipment (2 L to 30 L) for production of enzymes, and downstream protein purification equipment. Reactors for enzymatic saccharification, including high DM reactors (100 mL to 10 L)	Bioheat, biofuel, biogas, sustainability assessments
Norwegian Biorefinery Laboratory (Norbiolab) (PFI, SINTEF, NMBU, NTNU)	Trondheim, Ås	Lignocellulosics from forestry, marine biomass (seaweed)	Biochemical conversion: fermentation facilities up to 50L, up- and downstream processing equipment. Special fermentors for high cell density fermentations and high solid content/high viscosity; anaerobic fermentations; integrated product removal; pervaporation, hybrid distillation-membrane, membrane electrolysis, etc. Thermochemcial conversion: various gasifiers for catalytic conversion to alkanes and heavy alcohols. Slow and fast pyrolysis systems and infrastrcture for upgrading of pyrolysis oils through stabilization, catalytic hydrogenation, de-carboxylation. Separation technology: laboratory scale distillation, membrane and pervaporation systems; crystallization systems for recovery of compounds with high boiling points through freezing out technologies and phase separation	Biofuels, platform chemicals
National Facility for Marine Bioprocessing (Namab) (Nofima)	Tromsø	Marine biomass and residues	Handling of a large variety of biomass, Reactors for hydrolysis, Separators, two/three phase, Liquid phase separation, Purification of lipids, Water filtration (ultra/micro, nano, reverse osmosis), Concentration, evaporators, Mill dryer, hot air, Powder handling, Packaging	Marine ingredients for food/feed and pharma, hydrolysates, lipids, etc.

Central Biorefinery infrastructure (Hosts)	Location	Biomass used	Biorefinery/Methodology	Products/ Research areas
Barents Biocentre Lab (BBLAB) (UiT, NORUT)	Tromsø	Marine biomass, diverse marine resources	Molecular and microbiology equipment, Analysis equipment, Preparative equipment, Synthesis equipment. Main aim: bioprospecting for high value products from marine resources.	Marine high value products; pharma, enzymes, etc.

Norwegian Centre for Bioenergy Research, Ås (modified from http://www.bioforsk.no/)

The Norwegian Centre for Bioenergy Research is a collaborative initiative for research within renewable energy, mainly bioenergy. It was established by the three institutions located at the Ås campus: Norwegian Forest and Landscape Institute (Skog og Landskap), Norwegian Institute for Agricultural and Environmental Research (BIOFORSK) and Norwegian University of Life Sciences (NMBU). The Centre's research areas are bioheat, biofuel, biogas and sustainable assessments. The Centre's researchers work on the production of biomass from wood to its conversion into bioheat, and on the production of biogas from organic material like food waste, manure and municipal sludge. Expertise is combined for value chain projects which form the basis for sustainable analyses. The Centre cooperates with other research environments on specific technologies for the conversion of biomass into energy. It combines expertise from biology, technology, finance and the market and develops cost-effective energy solutions. The Centre documents the societal, environmental and economic consequences of the conversion of biomass into energy.

The Norwegian Centre for Bioenergy Research, in collaboration with the Norwegian University of Science and Technology (NTNU) and SINTEF, was appointed as one of eight of Norway's Centres for Environment-friendly Energy Research six years ago. This national centre is called Bioenergy Innovation Centre (CenBio) and is hosted by NMBU. CenBio constitutes the national research team within stationary use of bioenergy. Eighteen bioenergy companies are partners. CenBio concentrates on three tasks: i) increasing the volume of biomass produced in Norway for energy purpose, ii) improving the efficiency of biomass to energy conversion technology; and iii) improving the profitability of the bioenergy business.

Specific infrastructure available at the Norwegian Centre for Bioenergy Research and at CenBio is provided at the respective participating institutions, i.e. BIOFORSK, NMBU, NTNU and SINTEF, as detailed in section 2.1.3 below.

NorBioLab – Norwegian Biorefinery Laboratory – a central laboratory for biomass conversion, Trondheim/Ås (modified from http://www.pfi.no/ Biorefinery/Biorefinery-Projects/NorBioLab/)
NorBioLab will be a national laboratory for biorefining in Norway and is currently being established (from 2015). This involves the development of processes for sustainable conversion of Norwegian land and sea-based biomass into new, environmentally friendly biochemicals, biomaterials and bioenergy products. The laboratory will be available for national and international stakeholders. The Paper and Fibre Research Institute (PFI) is the project owner, with the Norwegian University of Science and Technology (NTNU), SINTEF and the Norwegian University of Life Sciences (NMBU) as key partners. NorBioLab aims to strengthen cooperation between national stakeholders involved in biomass conversion. Through the establishment of advanced research tools, the laboratory will help to develop new climate and environmentally friendly processes and products based on forest, agricultural and marine biomass, and to validate new technological processes before further implementation. The new research infrastructure will be a core tool to help develop technologies that lead to reduced greenhouse gas emissions and environmental impacts from both the transportation and industrial sectors, and also to help increase access to environmentally friendly products and energy. The infrastructure will be available to national and international universities, institutes and industry and will be located at the participating institutions in Trondheim and Ås. The new infrastructure will be closely integrated with existing infrastructure at PFI, SINTEF and NMBU as described below (2.1.3).

The NorBioLab infrastructure will include:

- For biochemical conversion:
  - Fermentation facilities up to 50L, including comprehensive up- and downstream processing equipment at the relevant scale for the fermentative production of biofuels and platform chemicals from biomass and biomass hydrolysates.
  - Special fermentors for high cell density fermentations and high solid content/high viscosity, as well as anaerobic fermentations with integrated product removal.

  - Separation systems for fuels and platform chemicals: ethanol, butanol; pervaporation and hybrid distillation-membrane (vapour permeation), membrane electrolysis, etc.
- For thermochemcial conversion:
  - Various gasifiers for generation of synthesis gas with subsequent catalytic conversion both to alkanes and heavy alcohols. Maximum capacity approximately 2kg/hr feedstock for largest gasifier. Catalysis systems generally built as microstructured systems where capacity is adapted through numbering up.
  - Pyrolysis systems (SINTEF and PFI) both slow and fast pyrolysis systems, capacity ranges from 100 gr/hr to 1.5 kg/hr. Upgrading of pyrolysis oils through stabilization and catalytic hydrogenation or decarboxylation.
- Separation technology:
  - Systems available for laboratory scale distillation (vacuum and pressurized), membrane and pervaporation systems with both organic and inorganic high-performance membranes.
  - Crystallization systems for recovery of compounds with high boiling points through freezing out technologies and phase separation NorBioLab is part of Norway's national strategy for research infrastructure 2012–2017, and as such is present in the Norwegian Roadmap for Research Infrastructure (see 2.1.6 for links to strategy documents).

National Facility for Marine Bioprocessing (NAMAB), Tromsø (modified from: http://nofima.no/)

Bioprocessing involves the use of biological components (enzymes etc.) in the treatment of various raw materials to yield other products such as proteins, peptides and oils. NAMAB (which opened in 2013) is a flexible mini-factory where high technology companies can test and optimize their processes to extract all desired components from marine and plant-based biomass and receive help to transfer promising research from the laboratory into advanced products on a larger scale. At NAMAB, companies can perform test productions based on their own processes and technology. NOFIMA can also collaborate with the companies in the development of these processes and technology. Smaller companies can rent the facility to perform periodic or regular production. At NAMAB, companies can test their production on a larger scale without the risk of large investments. From the test production, a cost estimate can be made and a product prototype can be tested in the market. In addition to commercial use, the facility is intended for use in research and for educational purposes.

NAMAB is located close to the laboratories and scale-up hall at the NOFIMA headquarters in Tromsø. NOFIMA can offer extensive experience in the development and scale-up of bioprocessing methods and has all necessary equipment for bioprocessing a large variety of biomass. Each type of biomass requires an optimized process to extract all desired components: water soluble, fat soluble and solids. Components produced are typically fish, bone and shell meal, purified oils, protein concentrate, small molecular components, bioactive peptides and ash. At NOFIMA, processes are optimized at lab scale and scaled up through a step-wise process to the small industrial scale.

The NAMAB processing plant is designed to receive most types of marine biomass, either preprocessed or raw/unprocessed. NAMAB is designed to be very flexible, allowing each company to design their process to meet exactly their own needs.

The NAMAB facilities include and enable:

- Handling of a large variety of biomass.
- Reactors for hydrolysis.
- Separators, two/three phase.
- Liquid phase separation.
- Purification of lipids.
- Water filtration (ultra/micro, nano, reverse osmosis).
- Concentration, evaporators.
- Mill dryer, hot air.
- Powder handling.
- Packaging.

2.1.3 Specialized research or engineering equipment of relevance for biorefinery technologies in Norway

This chapter presents specialized research and engineering equipment for biorefining at public and private research institutions in Norway active in the biorefinery field. Table 12 lists universities and research organizations active in the field of biorefinery R&D. Research infrastructure at these institutions is usually available within the frame of collaborative research activity involving the respective institutions.

In general, both the thermochemical (gasification, carbonization, pyrolysis, hydrothermal liquefaction) and biochemical routes (fermentation, enzymatic conversion, anaerobic digestions) for biomass conversion are well represented. Equipment for R&D on thermochemical processes are available at SINTEF MK (gasification, hydrothermal liquifaction, chemical catalysis), SINTEF ER (gasification, combustion, carbonization, HTL, pyrolysis), PFI (pyrolysis), UiA (gasification) HiT (gasification), and NTNU (gasification). Biochemical conversion process equipment is available at: NMBU (anaerobic digestion, enzymatic conversion, fermentation), SINTEF MK (fermentation, enzymatic conversion, strain development), HiT (anaerobic digestion), NAMAB/NOFIMA (enzymatic hydrolysis), BIOFORSK (anaerobic digestion), and UiA (anaerobic digestion).

Biomass pre-treatment equipment is available at PFI (pulping, steam explosion), NMBU (steam explosion), UiA (torrefaction), HiT (physical and enzymatic hydrolysis), Bioforsk (steam explosion), SINTEF ER (torrefaction), and NTNU (torrefaction). Process design, modelling and integration is regularly performed by SINTEF MK, NMBU, NTNU, HiT, and NOFIMA. Comprehensive and dedicated analytical equipment exists at SINTEF MK, SINTEF ER, HiT, UiA, PFI, NOFIMA and NMBU. Product generation and testing equipment is available at NMBU (feed, food, incl. feed trial possibilities) and NOFIMA. Algae cultivation equipment is available at BIOFORSK (seaweed, microalgae), UiA (microalgae), SINTEF FA (seaweed, microalgae) and NTNU (microalgae).

Table 12: List of universities and research organisations involved in developing the bioeconomy in Norway

Organization	Location	Type	Home page
Norwegian University of Life Sciences (NMBU)	*Ås*	*Academic Institution*	*www.nmbu.no*
Norwegian University of Science and Technology (NTNU)	*Trondheim*	*Academic Institution*	*www.ntnu.edu*
Telemark University College (HIT)	*Porsgrunn*	*Academic Institution*	*www.hit.no*
University of Agder (UIA)	*Kristiansand*	*Academic Institution*	*www.uia.no*
University of Bergen (UIB)	Bergen	Academic Institution	www.uib.no
University of Nordland (UIN)	Bodø	Academic Institution	www.uin.no
University of Oslo (UIO)	Oslo	Academic Institution	www.uio.no
University of Stavanger (UIS)	Stavanger	Academic Institution	www.uis.no
University of Tromsø (UIT)	*Tromsø*	*Academic Institution*	*www.uit.no*

Organization	Location	Type	Home page
Animalia	Oslo	Independent R&D institute	www.animalia.no
Barents Biocentre Lab	*Tromsø*	*Independent R&D institute*	*www.barents-biocentre.com*
Bioforsk (as of 1 July, 2015 part of the Norwegian Institute of Bioeconomy Research)	*Ås, Bodø*	*Independent R&D institute*	*www.bioforsk.no*
Institute of Marine Research (Havforskningsinstituttet, host of Marbank: biobank of arctic marine organisms)	Tromsø	Public R&D institute	www.imr.no www.imr.no/marbank/en
International Research Inst. Stavanger (IRIS)	Stavanger	Independent R&D institute	www.iris.no
Møre Research	*Volda*	*Independent R&D institute*	*www.moreforsk.no*
Nofima AS	*Ås, Tromsø, Bergen*	*Independent R&D institute*	*www.nofima.no*
Northern Research Institute AS (Norut)	Tromsø	Independent R&D institute	www.norut.no
Norwegian Forest and Land-scape Institute (Skog og Landskap, As of 1 July, 2015 Part of The Norwegian Institute Of Bioeconomy Research)	*Ås*	*Public R&D Institute*	*Www.Skogoglandskap.No*
Paper and Fiber Research Institute (PFI)	*Trondheim*	*Independent R&D Institute*	*Www.Pfi.No*
Sintef (Sintef Materials and Chemistry, Sintef Energy Research as, Sintef Fisheries and Aquaculture AS)	*Trondheim*	*Independent R&D institute*	*www.sintef.no*
Stiftelsen Det Norske Skogfrøverk	Hamar	Independent R&D institute	www.skogfroverket.no
Uni Research As	Bergen	Independent R&D institute	www.uni.no

1. Organizations with particular focus on biorefineries and the bioeconomy are in italic. Relevant infrastructures for biorefinery research are described under each organization in the text below.

Research or engineering equipment of relevance for biorefinery technologies at the different research organizations is presented below.

A. Norwegian University of Life Sciences (NMBU)

Features of laboratory facilities and infrastructure for biorefinery research at NMBU include:

- Steam explosion unit. 20 L reactor. Maximum 230 C.

- National biogas facility. 25 CSTR reactors in the range of 6–15 L. Batch bottles for BMP tests.
- Advanced analytical laboratory. A range of HPLCs and mass spectrometry for analysis of carbohydrates, organic acids and proteins.
- NMBU Biorefinery laboratory. Pilot scale laboratory for biomass processing. Milling, hydrolysis (up to 100 L reactors), separation equipment, spray drying.
- Enzyme production and application facility. Fermentation equipment (2 L to 30 L) for production of enzymes, and downstream protein purification equipment. Reactors for enzymatic saccharification, including high DM reactors (100 mL to 10 L).
- Fôrtek. Pilot scale facility for feed production.
- Food processing pilot plant. Processing of meat, cereals and milk.
- Animal feed trial facilities. Fish, chicken, pig and ruminants.

NMBU is partner in the Norwegian Centre for Bioenergy Research (together with BIOFORSK and Skog og Landskap) and NorBioLab (together with PFI, SINTEF and NTNU) (see 2.1.2) and interacts closely with most other organizations involved in bioeconomy research in Norway in multiple national research projects.

B. SINTEF
Three different units at SINTEF are involved in biorefinery R&D, i.e. SINTEF Materials and Chemistry (SINTEF MK, largest institute of the SINTEF foundation), SINTEF Energy Research AS (SINTEF ER), and SINTEF Fisheries and Aquaculture AS (SINTEF FA).

SINTEF covers most aspects of both the biochemical/sugar platform and the thermochemical platform of biorefinery research. Biotechnology activities at SINTEF MK also cover many additional aspects of turning natural resources into value added products for pharmaceutical, food & feed, fine and bulk chemicals, biofuel and other purposes. Different platforms with state-of-the-art equipment are accessible at SINTEF for use within the frame of bioeconomy-related collaboration projects together with commercial and academic partners.

Biorefineries based on abundant Norwegian biomass (wood, macroalgae/seaweed) is a prioritized research area at SINTEF, as is bioeconomy-related research in bioprocess technology, high-throughput screening, molecular biology/functional metagenomics, and advanced mass spectrometry. Also covered are macroalgae cultivation technology, gasification and chemical catalysis/thermochemical conversion.

Infrastructure platforms of relevance for biorefinery R&D available at SINTEF MK are:

- Comprehensive bioprocess technology platform for microbial cultivations from microliter to 300L pilot scale, including downstream processing for fractionation and product isolation; new specialized fermentation equipment especially designed for sugar platform applications, including integrated downstream process equipment to be established at SINTEF in Trondheim in 2015 within the frame of NorBioLab (see 2.1.2).
- One of Scandinavia's most complete and advanced mass spectrometry (MS) platforms for the analysis of complex mixtures, including a 12 Tesla FT-ICR-MS instrument that is unique in Scandinavia. The MS facilities are also one of Agilent's reference labs. The MS platform is well suited for analysis of complex biomass derived liquids (biomass extracts, biomass hydrolysates, pyrolysis liquids, lignins, complex carbohydrates, etc.). It is also well suited for Systems Biology-aided strain development by providing metabolome, flux and proteome data. The transcriptomics data part can be addressed by our Molecular Biology platform, while systems scale modelling and Synthetic Biology for strain development are covered by collaborating groups at NTNU.
- High throughput screening (HTS) platform for bioactivity assays, strain development and enzyme screening and optimization. Three robotic screening lines including colony picking and liquid handling and analysis up to 1,536 well format. Integration with the MS platform for high throughput MS analysis.
- Molecular Biology platform for metabolic engineering of e.g. biorefinery strains and Synthetic Biology R&D and monitoring microbial consortia and contaminations in bioprocesses, as well as functional metagenomics platform for the discovery and characterization of novel enzymes from environmental samples for bio-economy applications.
- Facilities for biorefinery catalyst R&D (laboratories for catalyst synthesis/preparation, diverse standard and advanced characterization instruments, set-ups for reaction kinetics study ranging from small-scale to mini-pilots, and equipment for analysis of products), both for synthesis gas conversion and pyrolysis oil upgrading.

- Gasification rigs:
  - Laboratory scale (“1g adsorbent”, flows < 0.5 l/min) set-up for performance testing of solid adsorbents (ceramic reactor) at high temperatures (H_2S removal from model feed (< 5,000 ppm S, etc.), with on-line MS analytical section.
  - Rig/set-up for reaction kinetics measurements or performance testing of for example water-gas-shift for syngas composition adjustment(WGS) or catalytic synthesis (biosyngas) to olefins or synthetic natural gas (SNG) at laboratory scale (“1g catalyst”, flows < 1 l/min, pressure < 5 bars).
  - Set-up for laboratory scale continuous mode (24/7) study of catalytic synthesis reactions at Fischer-Tropsch conditions (200–400 °C, < 30 bars) (4 parallel stainless steel reactors, on-line GC for gas/liquid products).
  - Set-ups (2) for laboratory scale continuous mode (24/7) study of catalytic synthesis reactions (oxygenates like MeOH, DME) at Fischer-Tropsch conditions (200–400 °C, < 30 bars) (stainless steel reactors, on-line GC for gas/liquid products).
- Hydrotreating rigs:
  - Micro-reactor test rig for continuous mode hydrotreating (hydrodeoxygenation, HDO) of bio-oil model feed (typically phenolics like phenol, anisole, guaiacol) at laboratory scale (“1g catalyst”, flows < 0.3 l/min, pressures < 150 bars, on-line analysis (HP5890 GC) of light gaseous products and off-line analysis (HP6850, autosampler). Adaptable in-house designed/constructed stainless steel reactors.
  - Set-up with stirred batch reactor (Parr 4540, 600 ml liquid volume, 350 °C, rig limited to 80 bars, H2 and N2), multi-purpose such as for hydrolysis of cellulose, or hydrodeoxygenation (HDO) or other reactions.
  - Mini-pilot scale set-up for continuous (24/7) hydrotreating (“100 ml catalyst range”, Gas flows < 3 l/min, liquid flow > 0.4 liters/hour, < 500 °C, <100 bars) in tubular stainless steel reactor (1" internal diameter, 1m length) for complex oils or model feed, with on-line GC for light gases (S and density measurements).

SINTEF MK collaborates for i.e. strategies and laboratories/equipment, with NTNU (Dept. Chem. Eng.) via the KinCat Gemini center.

Infrastructure platforms of relevance for biorefinery R&D available at SINTEF ER are:

- Entrained flow gasification reactor. Primarily used to study if a fuel is suitable for gasification towards biofuels as well as for heat and power, to study soot and tar formation from gasified biomass, and to provide validation data to numerical models. It is a flexible reactor not limited to gasification. It can also be used for combustion and pyrolysis purposes. Specs: Capacity: 2 Kg/h (~10–15 kW), Pressure: 10 bar (g), Temperature (1,500 ^{o}C), Continuous operating time: 6 h, Accessibility for external users after agreement.
- Torrefaction reactor for production of torrefied biomass. Specs: Capacity: 0.2–7 Kg/h, Pressure: atmospheric, Temperature: 200–300 °C, Fuel size: 1–25 mm, Accessibility for external users after agreement.
- Hydrothermal treatment for production of biofuels and biocarbon:
  - Batch carbonization reactor. Specs: Capacity: 250 mL, Pressure: 200 bar, Temperature: 400 °C, Accessibility for external users after agreement.
  - Continuous liquefaction reactor. Specs: Capacity: 1–5 mL/min, Pressure: 300 bar, Temperature: 550 °C, Slurry pump capacity: 500 mL, Accessibility for external users after agreement.
- Carbonization/pyrolysis reactor for production of biocarbon. Specs: Capacity: 50 g, Pressure: atmospheric, Temperature: 550 °C, Accessibility for external users after agreement.
- Design and development of wood and pellet stoves.
- Fuel storage and characterization:
  - Dedicated storage conditions.
  - Element analyser.
  - Bomb calorimeter.
  - High heating rate thermogravimetric analyzer (TGA).
  - Pressurized thermogravimetric analyzer (TGA).
  - Mass spectrometry.
  - Fourier transform infrared spectroscopy.
  - Ash melting analyser.

All SINTEF ER activities within bioenergy focus on thermochemical processes (gasification, combustion, pyrolysis, liquefaction, carbonization).

In addition, at SINTEF FA research comprehensive research infrastructure exists for processing of marine byproducts and for the cultivation of seaweed/macroalgae and microalgae.

C. Paper and Fibre Research Institute (PFI)

The Paper and Fibre Research Institute (PFI) is well-equipped and has a wide range of laboratory facilities and infrastructure for biorefinery research, including:

- Pretreatment/pulping equipment:
  - Mills, refiners, fibre separation units, multifunctional boilers – suitable for use both in relation to biochemical and thermochemical conversion pathways.
- Conversion tools:
  - Multifunctional reactors for conversion of biomass to a wide range of products (energy products, chemicals, material products), e.g. fast pyrolysis unit with catalytic upgrading (currently under establishment).
  - Rapid heating displacement reactor (also under establishment).
  - Homogenizers and mills for production of nanocellulose.
  - Extraction equipment.
  - Pellet press.
- Analytical equipment for:
  - Chemical analyses of lignocellulose and its components.
  - Physical characterization tools for fibers and fiber based products.
  - Morphological characterization tools for lignocellulose/fibers.
  - Energy characterization tools for evaluation of energy carriers.

PFI is coordinator of the Norwegian Biorefinery Laboratory NorBioLab (see 4.1.2) with SINTEF and NMBU as partners, and is located on the NTNU campus in Trondheim, together wth SINTEF MK and SINTEF ER.

D. Norwegian University of Science and Technology (NTNU)

Three out of four strategic thematic areas at NTNU are relevant for bioeconomy research, i.e. energy (including technological solutions for new renewable energy, and bioenergy), ocean science and technology (including sustainable seafood and clean energy from the ocean), and sustainability (including biodiversity and ecosystem services, and environmental and sustainability analysis). Consequently, NTNU's R&D activities within biorefineries lie within these topics.

At the Department of Energy and Process Engineering the focus is on thermal conversion of biomass for energy and product development. At EPT there are several lab facilities that are relevant for biomass thermal conversion technologies, including:

- Multi-fuel reactor for fundamental studies of pyrolysis, gasification and combustion of biomass.
- Small scale downdraft gasification rig.
- Lab scale torrefaction facility for pretreatment of biomass.

Furthermore, the Department has recently invested in an engine lab where final product fuels can be tested for combustion and emission characteristics including nitrogen oxides and particles (size and mass). Accessibility to external users is subject to availability and to direct costs being covered.

Fundamental analysis equipment of both pure and thermally converted biomass includes differential scanning calorimeter (DSC), bomb calorimeter, ash melting microscope TGA, and access to pressurized TGA.

At the Institute for Chemical Process Technology experience exists in modelling biorefinery-related processes, specifically wastewater. Modelling competence further includes process design, statistics and computational engineering applied to biorefining.

The Department of Biotechnology at NTNU has a long tradition of marine biopolymer research, and together with SINTEF the research focus includes alginates (a main component of seaweed biomass), chitosans. Extensive infrastructure exists for isolaton, fractionation, characterization (rheology, DSC, ITC, NMR, etc.) and modification of these marine polymers.

Comprehensive experience and research infrastructure for plant and microalgae cultivation and handling exists at the Department of Biology at NTNU.

E. Telemark University College (HiT)

Features of laboratory facilities and infrastructure for biorefinery research at HiT include:

- A range of lab and small pilot scale bioreactors used mainly to test biogas production from various wet organic (waste) sources.

- Bioreactors to grow microalgae to extract organic acids.
- Modeling tools for process simulations (biological and chemical processes, structures, particle transport and handling and fluid dynamics) and engineering.
- Analytical instruments to measure composition of products, intermediates, etc.
- Characterization of biomass feedstock: Bomb calorimeter, Thermogravimetric analysis, Differential scanning calorimetry.
- Product and exhaust gas analysis: GC, GC-MS, HPLC, IC, viscosimeter, densimeter.
- Biorefinery safety: > 10 yr experience in investigation of mist and gas explosions, based on e.g. CO, CO_2, H_2 air mixtures.

The total value of the above described bio-labs, built over the last 20 years, is about NOK 20 million and is available for external users on a project basis.

As mirrored by the above-mentioned infrastructure, biorefinery research activities at HiT include:

- Feedstock pretreatment: physical and biological disintegration and hydrolysis.
- Anaerobic digestion pilot plants: in lab and field with remote control and alarm systems.
- Gasification of biomass: 20 KW fluidized bed (hot) reactor, cold fluidized bed reactors used in conjunction with fluid flow and process modelling; software: Baracuda, Aspen plus, Ansys/Fluent. ECT (electrical capacitance tomography) analysis. Flashpoint determination.
- Process safety: high speed cameras and custom designed riggs combined with theoretical modelling.

F. University of Agder (UiA)
Renewable energy is a research priority area at UiA, including bioenergy and thermal energy, i.e. research on interactions between biomass characteristics and applications, characterisation of biomass, especially energy crops, thermo-chemical energy conversion of biomass, and microlgae production.

Laboratory facilities and infrastructure for biorefinery research at UiA include:

- Gasification equipment:
  - fixed-bed downdraft gasifier with a 3 cylinder Kubota natural gas engine coupled with a 5 kW DC power generator.
  - Bubbling fluidized-bed gasifier, together with HiT.
- Biofuel boiler for firewood, wood pellets, grain, and wood chips.
- Wood pellet stove, 6 kW Wodtke Smart, with electric ignition, hopper capacity 25 kg.
- Dryer for wood and straw.
- Briquette press, 45 mm briquettes.
- Hammer Mill.
- Gas and oil furnaces, 100 kW, with see-through glass and adjustable fuel and air nozzles.
- Photobioreactor system for microalgae production.
- Analysis equipment (Heating Microscope, 1,750 °C, Online producer gas analysis CO, CO2, CH4, H2, O2, Portable chilled mirror hygrometer for determination of dew point, Gas chromatograph, Micro gas chromatograph, Adiabatic bomb calorimeter for measuring the calorific value, Elemental analyzer C, H and N, Thermogravimetric analyzer (TGA), Heated muffle furnace for measuring ash content, 1,100 °C, Drying oven for measurement of moisture content, Flue gas analysis CO, O2, flue gas temperature and draught, Measurement of moisture content by means of conductivity, Measurement of moisture content capacitive, 2 food calorimeters, Thermocouples for measuring flue gas temperature, pallet scales 1,500 kg).

G. NOFIMA
NOFIMA is one of the largest institutes for applied research within the fields of fisheries, aquaculture and food research in Europe. The main areas of research include breeding and genetics, capture-based aquaculture, consumer and marketing research, consumer and sensory sciences, fish health, food and health, food safety and quality, industrial economics and strategic management, marine biotechnology, nutrition and feed technology, processing technology, production biology, raw materials and process optimisation, and seafood industry.

Related to biorefinery R&D, extensive experience exists at NORFIMA within the field of bioprospecting, bioprocessing and scale up of processes in order to exploit and preserve value in raw materials from the ocean for sustainable feed, food and health.

NOFIMA operates the National Facility for Marine Bioprocessing NAMAB (see 2.1.2), an integrated bioprocessing plant designed to run a variety of different processes using the infrastructure described above (2.1.2), including hydrolysis with post processing including decanting, separating and drying from most types of marine biomass; fresh, frozen or preprocessed. The plant is approved for production of marine products intended for human consumption.

H. Norwegian Institute of Bioeconomy Research (NIBIO) (established 1 July, 2015)

As of 1 July, 2015, the Norwegian Institute for Agricultural and Environmental Research (BIOFORSK), the Norwegian Forest and Landscape Institute (Skog og Landskap) and the Norwegian Agricultural Economics Research Institute (NILF) have been merged into the Norwegian Institute for Bioeconomy (NIBIO (see also 2.1.6). NIBIO will be Norway's largest interdisciplinary research institute within agriculture and the environment and will combine the research infrastructure that is available at its three pedecessors today, including:

- Modern field trial and greenhouse facilities.
- A highly advanced biogas lab, together wih NMBU, from laboratory to pilot scale, including microbiology labs.
- Laboratory for cultivation and studies of microalgae.
- Two molecular biology labs.
- Cultivation systems for macroalgae/seaweed.
- Laboratory for studies of fish aquaculture linked to cleaning systems and algae cultivation.
- Steam explosion equipment for pretreatment of substrates (together with Cambi AS and NMBU).

NIBIO will be also take on the roles of BIOFORSK and Skog og Landskap as partners in the Norwegian Centre for Bioenergy Research (see 2.1.2), together with NMBU.

I. University of Tromsø (UiT)

At UiT, research at the faculty of Biosciences, Fisheries and Economics is of particular interest with respect to biorefinery research with its topic marine bioprospecting, fish health, and marine alimentary products.

Relevant Research Centres at UiT with infrastructure of relevance to biorefinery R&D based on in particularly marine biomass include:

- The Centre of Marine Bioactives and Drug Discovery (MabCent) and its successor the Arctic Biodiscovery Centre (Marine bioprospecting).
- The Norwegian Structural Biology Centre (protein production, structure determination, drug discovery and design, high throughput crystallization facility).
- Centre of Marine Resource Management – MeReMa.

J. Barents Biocentre Lab (BB Lab)

Barents Biocentre Lab (BB Lab) is an infrastructure project initiated by several biotech companies, the University of Tromsø, NORUT (Northern Research Institute) and Norinnova Technology Transfer. BB Lab offers access to modern laboratories with advanced equipment for biotechnology companies, research communities and educational institutions. BB Lab targets in particular work in the areas of marine bioprospecting, lipids and proteins/enzymes/peptides.

The list of principal instruments at BB Lab includes:

- Molecular and microbiology equipment (e.g. Real-Time PCR, DNA sequencer MiSeq, Autom. analysis equip. 2100 eBioanalyzer, DNA size selection and collection system Pippin Prep, Protein Interaction Analysis system Biacore T200, Power-prep/Sample clean up system).
- Analysis equipment (e.g. Ultra Performance Liquid Chromatography–Triple Quad MS/MS and -H-Class, GC-tandem mass spectrometry system Quattro Micro GC-MS/MS, Mass Spectrometer Xevo G2 QTof, Isothermal titration calorimeter, Dissolution Testing Equipment).
- Preparative equipment (e.g. Preparative Liquid Chromatography, MicroReactor System Micro-24, Cascade and Console Freeze Dry System, Fast Protein Liquid Chromatography – Äkta purifier).
- Synthesis equipment (e.g. Peptide synthesizer PPS-220C PRELUDE system, Manual Microwave Assisted Peptide Synthesizer, Parallel Synthesis Station, Nitrogen and Steam generators).

Clusters and funding agencies

In addition to the companies and research institutions given above and in section 2.1.2, a number of networks and clusters exist of relevance to the bioeconomy in Norway. Table 13 lists these clusters, as well as the main funding bodies in Norway supporting R&D in this field. Many of the companies listed in Table 11 are members or participants of these clusters whose main purpose is to serve as a meeting place for exchange of knowledge and information. Research infrastructure within these clusters consists of the privately owned equipment at the participating companies and institutions.

Table 13: List of clusters and funding bodies supporting the development of the Bioeconomy in Norway

Organization	Location	Type	Home page
Biotech North	Tromsø	Network / cluster	www.biotechnorth.no
Norwegian Seafood Federation (Fhl)	Oslo	Network / cluster	www.fhl.no
Green Business Norway	Skien	Network / cluster	www.greenbusiness.no
Hedemark Kunnskapspark	Hamar	Network / cluster	www.hkp.no
Herøya Industrial Park	Prosgrunn	Network / cluster	www.heroya-industripark.no
Industrial Biotechnology Network Norway	Trondheim	Network / cluster	www.indbiotech.no
Marelife	Oslo	Network / cluster	www.marelife.no
Nho Mat Og Landbruk	Oslo	Network / cluster	www.nhomatoglandbruk.no
Norwegian Bioindustry Association	Oslo	Network / cluster	www.biotekforum.no
Omegaland/Legasea	Ålesund	Network / cluster	www.omegaland.no
Siva	Trondheim	Network / cluster	www.siva.no
Stiftelsen Fiskeriforum Vest	Bergen	Network / cluster	www.fiskeriforum.no
Trefokus	Oslo	Network / cluster	www.trefokus.no
Treklyngen As	Follum	Network / cluster	www.treklyngen.no
Ålesund Kunnskapspark As	Ålesund	Network / cluster	www.aakp.no
The Research Council Of Norway	Oslo	Funding Agency	www.forskningsradet.no
Innovation Norway	Oslo	Funding Agency	www.innovasjonnorge.no
Regional Research Funds In Norway	Diverse	Funding Agency	www.regionaleforskningsfond.no
Enova		Funding Agency	www.enova.no
Norinnova	Tromsø	Funding Agency	www.norinnova.no

One commercial cluster of particular relevance for a potential future biorefinery in Norway is Treklyngen AS (also included in (Table 11). As an innovation branch of Viken Skog SA, one of the largest forest owner cooperatives in Norway, this cluster aims at co-localizing complementary companies on the site of the abandoned paper mill at Follum/Hønefoss for integrated biorefining of woody biomass.

2.1.4 Advanced technologies of relevance for improved biorefineries in the Norwegian research community

The details of relevant infrastructures at Norwegian research organizations and companies given in sectons 2.1.2 and 2.1.3 reflect the current capabilities in Norway to perform advanced biorefining.

Advanced technologies currently being used, developed further and optimized by the Norwegian research community include:

- High rate biogas reactor technology adapted for challenging feeds (HiT, UiA, NMBU, BIOFORSK).
- C6 and C6/C5 Sugar Platform (PFI, SINTEF MK, NTNU, NMBU).
- Lignin Platform (PFI, SINTEF MK).
- Hydrothermal liquefaction (SINTEF MK/ER).
- Pyrolysis oil platform (PFI, SINTEF MK/ER, NTNU).
- Plant based Oil platform (PFI).
- Gasification and Fisher-Tropsch synthesis (SINTEF ER/MK, NTNU).
- Macroalgae cultivation (BIOFORSK, SINTEF FA).
- Microalgae cultivation (SINTEF FA/MK, HiT, UiA, NTNU).
- Processing of marine biomass and wastes for high value products (NOFIMA, UiT, SINTEF FA).
- Novel, green biomaterials such as biocomposites, nanocellulose and other green products of central importance to future biorefinery concepts (PFI).
- Process modelling and design and computational engineering related to biorefining (NTNU, NMBU).
- Model development for thermal conversion of biomass resources (NTNU, SINTEF ER/MK), including simulations of reacting multiphase flow systems such as gasification and biocarbon production reactors.
- Advanced semi in-line IR methodology for hydrolysis monitoring (NAMAB/NOFIMA).
- High throughput robotics for automatic micro-cultivation and analysis of fermentation processes (SINTEF MK).
- Biorefinery strain development using classical approaches, systems biology, metabolic engineering and synthetic biology. (SINTEF MK, NTNU).
- Advanced chemical analysis of complex mixtures (wood liquids, lignins, bio-oil, etc.) using mass spectrometry (SINTEF MK, NMBU).
- Industrial enzymes for biomass conversion; discovery and development (NMBU, SINTEF, Uni Research, UiB, UiT, NOFIMA).
- Bioprocess technology (fermentation, up-scaling, process integration; SINTEF, NMBU, NTNU).

2.1.5 Biorefinery-relevant processes for which special expertise exists in Norway

Biorefinery-relevant processes for which special expertise exists in Norway, include:

- Biomass pretreatment and hydrolysis:
  - Physical and chemical pretreatment.
    - Steam explosion (Cambi AS).
    - Sulphite pulping.
    - Termomechanical pulping (TMP).
    - Chemo-thermomechanical pulping (CTMP).
  - Chemical hydrolysis.
  - Enzymatic processing of lignocellulose including use of oxidative enzymes.
- Thermochemical conversion technologies:
  - Pyrolysis.
  - Gasification.
  - Hydrothermal liquefaction.
  - Combustion (for stationary energy).
- Biochemical conversion technologies:
  - Fermentation.
  - Microbial communities in biogas reactors.
  - High rate biogas production.
- Production of speciality chemicals from softwood by integrated biorefining (Borregaard AS).
- Biobased development of food&feed ingredients by bioprocessing of marine and land based feedstock.
- Use of marine resources for added-value product generation (e.g. pharmaceuticals/ nutraceuticals/ food&feed ingredients):
  - Processing of marine residues (fish, Crustacean, etc.).
  - Seaweed cultivation.
  - Seaweed harvesting, processing, fractionation (FMC Biopolymer AS).
  - Enzymatic processing of marine carbohydrates (alginate, chitosan, etc.) for high value product generation (Algea AS).

- Generic expertise from fossil processes (petrochemistry and refinery processes) which are transferable to biorefinery processes.
  - Process modelling and design.

2.1.6 National priorities and recommendations (links to official strategies)

Recent national strategies exist in Norway for several aspects related to the bioeconomy and biorefineries. The national strategy SKOG22 2015:

- https://www.regjeringen.no/nb/dokumenter/skog-22--nasjonal-strategi-for-skog--og-trenaringen/id2363770/

Covers the future use of Norwegian forests and also includes the use of woody biomass for the bioeconomy. A comparable national strategy for the marine sector exists in HAV21 2011:

- http://www.hav21.no/

A National Strategy for Biotechnology covers the central technological aspects of relevance for the Bioeconomy 2011:

- https://www.regjeringen.no/nb/dokumenter/nasjonal-strategi-for-bioteknologi/id666235/

Also a National Cross-sectoral Biogas Strategy exists in Norway 2014:

- https://www.regjeringen.no/contentassets/255fa489d18d46feb3f8237bc5c096f0/t-1545.pdf

These national strategies are reflected in several large programmes of the Research Council of Norway, including the BIONÆR programme (Sustainable Innovation in Food and Biobased Industries:

- http://www.forskningsradet.no/servlet/Satellite?c=Page&pagename=bionaer%2FHovedsidemal&cid=1253971968584&langvariant=en

The ENERGIX programme (Large-scale programme for energy research):

- http://www.forskningsradet.no/servlet/Satellite?c=Page&pagename=energix%2FHovedsidemal&cid=1253980140037&langvariant=en

The HAVBRUK programme (Aquaculture – An Industry in Growth):

- http://www.forskningsradet.no/prognett-havbruk/Home_page/1226994216880

The MILJØ2015 programme (Norwegian environmental research towards 2015):

- http://www.forskningsradet.no/prognett-miljo2015/Home_page/1224697848161

The BIOTEK2021 programme (Biotechnology for innovation):

- http://www.forskningsradet.no/servlet/Satellite?c=Page&pagename=biotek2021%2FHovedsidemal&cid=1253970728155&langvariant=en

A regional policy is also implemented by the Research Council of Norway to promote the use of more research in regional development activities:

- http://www.forskningsradet.no/en/Newsarticle/The-Research-Council-strengthens-regional-efforts/1253996157043/p1177315753918

In addition to the existing strategies, a National Strategy for the Bioeconomy in Norway is currently under development and expected to be finalized by the end of 2015. An important feature will be a central office across the different relevant ministries to coordinate this cross-sectoral strategy. In preparation for this new strategy, a conference with key national players in the field is planned for the middle of June 2015.

One important step towards this new strategy is the previously mentioned establishment of a Norwegian Biorefinery Laboratory (NorBioLab) as part of Norway's national strategy for research infrastructure 2012–2017:

- http://www.forskningsradet.no/prognett-infrastruktur/National-strategy-for-research-infrastructure/1253976458361

Which is referred to in the Norwegian Roadmap for Research Infrastructure:

- http://www.forskningsradet.no/prognett-infrastruktur/Norwegian-Roadmap-for-Research-Infrastructure/1253976312605

Also, recently, the Norwegian government has announced the establishment of a new Norwegian Institute for Bioeconomy Research (NIBIO, see 2.1.3 H):

- https://www.regjeringen.no/nb/aktuelt/norsk-institutt-for-biookonomi-nibio-opprettes-1.-juli-2015/id2394764/

Which will be Norway's largest institute specifically dedicated to bioeconomy research.

In May 2015, the Research Council of Norway announced a total of NOK 900 million for research based innovation for Norwegian industry:

- http://www.forskningsradet.no/en/Newsarticle/NOK-900-million-available-for-researchbased-innovation-for-industry/1254008982723/p1177315753918

Innovation, sustainability and a more environmentally friendly business sector are key themes of this year's call for proposals. NOK 250 million of the total funding available is earmarked for green growth and societal transition, among other things to help supplier industry companies to enter the renewables industry.

2.1.7 Exisiting biorefineries in Norway

The most significant biorefineries existing in Norway are:

- Borregaard AS (integrated lignocellulose-based biorefinery; see 2.1.2 for details).
- FMC Biopolymer (alginate and other high value compunds from seaweed biomass).
- CAMBI AS (biogas and fertilizer by anaerobic digestion, technology supplier).
- Norske Skog AS (paper and by-products from woody biomass).

Refer also to Table 10 in section 2.1.2, which list bioeconomy companies in Norway that produce single or multiple products from the diverse abundant Norwegian biomasstypes described in 2.1.1.

2.1.8 Main products produced (or under development) in Norway from biorefineries

The following products and product classes are produced from biorefineries and bioeconomy companies in Norway:

From lignocellulosic biomass and residues (forestry and forestry residues, agricultural residues):

- Bulk and speciality chemicals (Borregaard AS):
  - Bioethanol.
  - Lignosulfonates.
  - Dissolving pulp.
  - Vanillin.
  - Microfibrillated cellulose.
- Chemical Thermo Mechanical pulp (CTMP, MM FollaCell).
- Thermo Mechanical pulp (TMP, Norske Skog AS).
- Feed ingredients (discussed).

From fisheries and aquaculture residues (several companies, see Table 10):

- Omega 3-rich oils.
- Protein hydrolysates.
- Chitin, chitosan.
- Enzymes.
- Pharmaceuticals.
- Animal feed products (aquaculture, land-based).
- Other food/feed ingredients and nutraceuticals.

From macroalgae/seaweed (FMC Biopolymer AS):

- Alginate.
- Fucoidan.

From MSW and other industrial waste streams:

- Biogas (Cambi AS, Biokraft AS).
- Fertilizer products.
- Minerals for soil.

From diverse biomass (thermochemical routes):

- Diesel/gasoline via bio-Fischer-Tropsch; (cancelled 2008/9).
- Aviation fuels (planned, Avinor, Viken skog – Research Council Projects, etc.) via gasification route.
- Bio-oils (planned, Tofte site, joint venture between Sødra AS and – Statkraft AS (= Silva Green)), liquid routes towards Bio-jetfuel.
- Transportation fuels for heavy road transport, marine transport and the aviation sector (FT-jet fuel, biodiesel, biocrude, syngas, pyrolysis oil).
- Syngas for multiple products (methanol, DME, ethylene, propylene, etc.).
- Bioheat and biopower (district heating, CHP, wood and pellet stoves).
- Ash utilization (byproduct) for the cement industry.
- Combined biocarbon and pyrolysis oil production for sustainable biocarbon as reduction agent in metallurgic industries (Elkem AS).
- Electricity, steam and biogas for transport after cleaning via thermal hydrolysis route (Cambi AS).
- Biogas from land-based and marine residues.

2.1.9 References

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2.2 Bioeconomy in Finland

Kristiina Hildén and Miia Mäkelä. Department of Food and Environmental Sciences, University of Helsinki, Finland

2.2.1 Bioresources in Finland

Finland is one of the leading users of renewable energy sources, especially bioenergy, in the world. Use of renewable energy sources accounts for a quarter the total energy consumption and more than a quarter of power generation. Wood and wood-based materials make up the largest proportion of the biomass-based energy resources (Table 14). Forestry, forest-based industries and agriculture are the main bioresources for current biorefineries in Finland. Marine resources are also seen as a promising element in the Finnish bioeconomy but they are still poorly utilized.

Table 14: The most important bioresources in Finland

Forestry residues and waste	Potential for the production of 15 TWh
Agricultural residues and waste	Potential for the production of 12–22 TWh energy
Municipal waste	200,000 t as oil equivalent/year

The efficient use of bioresources requires their full potential be used, based on a value cascade, where the most valuable products are taken out first followed by use of sugars for production of bioenergy. Another important aspect is the logistics of forest biomass with synergy benefits for local companies, regional commitment, and availability of competent labor.

A larger share of energy consumption in Finland is met by the use of biomass than in any other industrialised country. In recent years energy derived directly or indirectly from wood has accounted for around 20% of Finland's total energy consumption (http://www.mmm.fi/en/index/frontpage/forests/climate_energy/forest_biomass.html). Up to 97.5% of the bioenergy produced in Finland is from wood and wood-based residuals originating from scale pulp and paper industry, including black liquor derived from pulp-making processes. The remaining 2.5% of the bioenergy is derived from solid recovered fuels, biogas, energy crops and organic liquid fuels.

The forest industry companies produce large amounts of energy (about 70 TWh/year) from side streams of the forest industry such as bark, woodchips and sawdust, and from byproducts of pulp and paper processes, such as black liquor, thus maximizing the utilization of forest biomass.

At the moment, forest biomass is mainly used in large-scale CHP-plants (combined heat and power) in the forest industry and communities. There are also numerous district heating plants using forest biomass (Laihanen *et al*., 2013).

Forest biomass is estimated to be the main source of bioenergy to achieve the national target of 38% renewable for final energy consumption by 2020. The Finnish national climate and energy strategy envisages increase in use of forest chips in the generation of heat and power, corresponding 25 TWh of energy (http://www.tem.fi/en/energy/energy_and_climate_strategy/strategy_2013). One aim of the strategy is that the amount of energy generated from logging residues should triple by 2020. The strategy also suggests increase in use of wood pellets, and production of wood-based liquid biofuels, which could be used instead of oil-based fuels for heating and transportation. Wood-based raw material also has significant potential to produce bio-SNG.

Logging residues from foresty, including treetops, stumps and branches, together with byproducts from forest industry, can also be utilized in the manufacture of liquid biofuels suitable for road vehicles. At the moment, related biorefining techniques and business concepts are being tested and developed in Finland. The world's first wood-based renewable diesel biorefinery has started commercial production in Lappeenranta, Finland, and uses wood-based tall oil from its own production processes. The biorefinery will produce annually approximately 100,000 tonnes of biodiesel per 120 million litres tall oil. Crude tall oil is pretreated followed by hydrotreatment, recycle gas purification and fractionation, resulting in renewable diesel BioVerno (http://www.upmbiofuels.com). BioVerno has been recognised as a breakthrough innovation in sustainable production technology and was awarded the Sustainable Energy Europe 2014 Award by the European Commission. Crude tall oil is a versatile raw material that can be refined for a wide range of uses. In Finland, tall oil is used in various detergents, cosmetics, alkyd paints and Benecol food products, which include plant sterols and stanols manufactured from tall oil fractions.

The world's first next-generation bioproduct mil, which can convert wood raw material into a diverse range of products, is planned to be built in the existing mill area in Äänekoski, Finland. The mill will produce high-quality pulp, bio-energy and various biomaterials in a resource-efficient way (http://www.metsafibre.com). The mill will use only wood raw material and side streams for products and bio-energy without using any fossil-based fuels. A unique bioeconomy ecosystem of companies will be built around pulp production. This initiative is estimated to be the largest ever investment (approximately EUR 1.1 billion) in the forest industry in Finland. The new mill which will have an annual pulp production capacity of 1.3 million tonnes is planned to be operational in 2017.

As the paper industry in Finland has been downsized, forest industry has been forced to explore new business opportunities to use wood for innovative value added products. Instead of pulp, wood fibres can be processed into biocomposites, biofibrils, biochemicals and fertilizers. For example, VTT Technical Research Centre of Finland Ltd (http://www.vttresearch.com/) has developed tannin extraction from softwood bark. In Finland, tannin could replace fossil chemicals in adhesives and insulating foams and fossil-based phenols in adhesives that are used in the wood products industry. Efforts to transform lignin into value added products have been started in Finland where EUR 32 million investments have been made to build a world-class biorefinery at Sunila Mill in Kotka, Finland. Sunila Mill has an annual capacity of 370,000 tonnes of softwood pulp, and the LignoBoost plant will be integrated with the pulp mill to extract lignin from the black liquor. The new biorefinery will reduce CO2 emissions of the mill by replacing appr. 90% of natural gas with dried lignin fired in the lime kilns. In addition, lignin can be used as a sustainable alternative for phenols in plywood glues and other wood-based panels, and polyols used in foams. The investment is expected to generate annual sales of EUR 80 million (http://biconsortium.eu/news/stora-enso-invests-world-class-biorefinery-sunila-mill-finland#sthash.YFpE72xa.dpuf, www.valmet.com).

VTT has also developed a method to produce BTX chemicals, benzene, toluene and xylene, by combining the gasification of lignocellulosic biomass, the Fischer-Tropsch synthesis and aromatisation. The method could be used in the production of biobased chemicals to replace crude oil in the manufacture of, for example, plastics, fuels, medicine and paints.

Agricultural crops in Finland are mainly barley, oat, wheat and rye. Field residues such as straw and processing residues such as husks and chaff can be used for biofuel production. Currently, only a relatively small part of bioenergy produced in Finland originates from energy crops, recovered fuels, liquid biofuels or biogas. However, their importance is growing fast as climate-friendly alternatives to replace non-renewable fossil fuels. The Ministry of Agriculture and Forestry of Finland has set a target to increase the field area of energy crops to 100,000 ha before 2016 (http://www.aebiom.org/wp-content/uploads/file/Publications/Handbook%20for%20energy%20producers.pdf).

Reed canarygrass is the most common energy crop in Finland. The bioenergy potential of the Finnish field crop production could be as high as 12–22 TWh, or 3–5% of the total energy consumption in Finland in 2008 (Mikkola, 2012). The major part of this energy would originate from straw and reed canarygrass cultivated for energy use. However, only 0.5 TWh of this potential is utilized.

A variety of non-food biomass generated as agricultural byproducts can be utilized as feedstock for biofuels and biogas. Recently, the Ministry of Employment and the Economy in Finland granted EUR 30 million for a planned bioethanol facility investment in Myllykoski (Bioethanol Finland Oy). The project will utilize the existing infrastructure, such as power plants, sewage treatment plants and complete logistics connections. The refinery is planned to produce about 72,000 tonnes of bioethanol per year from straw.

The potential of other valuable fractions from non-food feedstocks has also been studied. In an EU-funded project APROPOS, VTT developed biomechanical methods to extract proteins and phenols from rapeseed oilpress cake for applications in the food and cosmetics industry. Rapeseed oilpress cake, a side-stream from production of rapeseed oil, is currently used in animal feed production. In the future, this protein and other valuable substance containing fractions could be used as a food ingredient, thus increasing their commercial value even up to EUR 5,000/tonnes. Annually, 50,000 tonnes of rapeseed oilpress cake is produced in Finland.

Renewable diesel production uses waste and residue-based raw materials, such as animal fat from slaughterhouse waste, oily waste from the food industry and restaurants. Fish-processing byproducts are also used, though biomass from fisheries is a minor resource in Finland. The integrated BioGST biorefinery combines the use of variable biobased raw materials and its outputs include biodiesel, biogas, biomethane, vehicle biofuels, electricity, thermal energy, glycerol, fertilizer/soil improvement medium (http://www.biogts.com/integrated-biorefinery/). The BioGTS biorefinery combines the advantages of biogas and biodiesel production, and the process residues can be used in parallel processes due to the closed process cycle.

Fish biomass is an underutilized renewable resource in Finland. Approximately 14 million kg of byproducts was created in the fish processing industry in 2009, a significant proportion of which can be used for fur animal feed and only some for food and bio-oil and biofuel production. Optimal utilization of biomass includes separation of value added ingredients for food and feed industry, for example fish protein for fish feed, while the remaining fractions would be directed to biogas and biodiesel production. See Table 15 Sybimar Oy and Biolinja Oy.

2.2.2 Finnish strategy for bioeconomy

The Finnish strategy for the bioeconomy aims to generate a competitive operating environment for the bioeconomy, new business from the bioeconomy, a strong bioeconomy competence base and accessibility and sustainability of biomasses (http://www.tem.fi/files/40366/The_Finnish_Bioeconomy_Strategy.pdf). In Finland the goal is to increase the bioeconomy output up to EUR 100 billion by 2025 and to create 100,000 new jobs. The most recent energy and climate strategy in Finland was approved by the Government in 2013 (http://www.tem.fi/en/energy/energy_and_climate_strategy/strategy_2013). The long-term goal of Finland is a carbon-neutral society, which is foreseen to be reached by increase in energy efficiency and by the use of renewable energy. In order to reach the long-term goals, the Energy and Climate Roadmap 2050 was published in 2014 to serve as a strategic guide in Finland until 2050 (http://www.tem.fi/en/current_issues/pending_projects/strategic_programmes_and_flagship_projects/energy_and_climate_roadmap_2050).

The basis of the new bioeconomy business opportunities in Finland will be novel exploitation of water resources and biomass, and the development of technologies for these resources in order to achieve high added value products and services. The aim is the more diverse use of biomasses from forestry and agriculture and use of hitherto underexploited biomass resources for new products and materials. The current boundaries between different sectors will also disappear and create new value networks. Local interaction between sectors and services will support the exploitation of sidestreams for their efficient use.

Centres of expertise and reform of the priorities and operating models of research are needed for a competitive bioeconomy. Cross-sectoral activities that create innovative solutions and improve competitiveness are bioeconomy cooperation platforms (Strategic Centres for Science, Technology and Innovation (SHOK) Centres, Innovative Cities (INKA) programme, research cooperation models), pilot and demonstration projects in cooperation with financial instruments of the EU programming period 2014–2020, and domestic, public and private R&D&I funding. This will require deeper cooperation between universities and research institutes, and especially opportunities for business development within the bioeconomy besides the research, development and innovation activities.

2.2.3 Research for biorefinery technologies and bioeconomy business in Finland

The main universities and research institutes for the bioeconomy in Finland are Aalto University, Lappeenranta University of Technology, Tampere University of Technology, Oulu University, University of Helsinki, University of Turku, University of Jyväskylä, Natural Resources Institute Finland, VTT Technical Research Centre of Finland Ltd and Finnish Environment Institute.

At Aalto University (www.aalto.fi/en), located in Espoo, one of the key research areas is materials and sustainable use of natural resources. The main focus is on development of new fractionation methods of the polymeric constituents of lignocellulose and their conversion into high value added products.

Biorefinery-related research at Lappeenranta University of Technology (http://www.lut.fi/web/en/) concentrates on development of products achieved through biorefining separation and purification. The focus is wood based raw materials including their fractionation and purification. In addition, the main interests comprise developing and improving forest biorefinery processes, and recovery of hemicelluloses and hydroxy acids. Facilities of Lappeenranta University of Technology support pilot scale research on biorefining.

Tampere University of Technology (http://www.tut.fi/en/) has research projects focusing on the utilization of biomass-based waste streams and materials for the production of bioenergy.

Oulu University (http://www.oulu.fi/english/) is a part of the bioeconomy research community Oulu (BRC-OULU; http://www.oulu.fi/bioeconomy/), which is a researcher-driven network of active research groups which works on biomass conversion and valorization. The BRC-OULU research community has expertise in biology, chemistry and biomass conversion technologies and its aim is to activate local and national bioeconomies through participation in European and global research networks.

The University of Helsinki (https://university.helsinki.fi/en) has various research groups focusing for example on valorization of sidestreams from forestry and agriculture, and the dairy industry.

The University of Turku (http://www.utu.fi/en/Pages/home.aspx) has molecular biosciences, including plant biological research on bioenergy, as an area of strength in research. In addition, the research includes conversion and valorization of various biomass (see for excample Table 15 for Cursor Oy).

One of the main research areas at the University of Jyväskylä (https://www.jyu.fi/en/) is bio- and waste refineries that use thermochemical conversion of mainly solid feedstocks. The feedstocks include wood, residues from forestry and agriculture, and solid waste, while the products include biogas, hydrogen, FT-diesel and ethanol.

The Natural Resources Institute Finland (http://www.luke.fi/en/) is a research and expert organisation that promotes the bioeconomy and sustainable use of natural resources. It consists of four research units, a statistics unit and an internal services unit, which take part in multidisciplinary research programmes and projects in collaboration with Finnish and international partners. The focus of the Natural Resources Institute Finland is on forest biomass and development of sustainability and competitiveness of the food system.

VTT Technical Research Centre of Finland Ltd (http://www.vttresearch.com/) provides technology solutions and innovation services for Finnish and international customers and partners in both the private and public sectors. Their focus is on food, bioenergy and biofuels, biochemicals, and biomaterials as well as bioeconomy-related technologies.

The Finnish Environment Institute (http://www.syke.fi/en-US) is a research institute and a centre for environmental expertise. The institute forms part of the national environmental administration in Finland and its main tasks include research, development and production of various services. Their research has been focusing on for example planktonic algae as a resource in bioenergy production.

The most important public funding bodies in Finland are the Academy of Finland, the Finnish Funding Agency for Innovation (Tekes) and The Finnish Innovation Fund (Sitra). The Academy of Finland provides research project, infrastructure and program funding, and it also funds strategic research programmes. Tekes provides innovation funding for companies, research organisations, and public sector service providers with a specific focus on SMEs. Recently, Team Finland's Sustainable Growth campaign, funded by Tekes, Export Finland (Finpro), Finnvera and the Centres for Economic Development, Transport and the Environment, issued a call aiming to activate Finnish SMEs in bioeconomy and cleantech (https://www.tekes.fi/en/whats-going-on/application-schedules/teamfinland-funding-application-round-and-international-services-under-the-theme-sustainable-growth/). Sitra provides funds for surveys, forward-thinking activities, experiments, and shared strategy processes that promote well-being and are ecologically and socially sustainable. The Academy of Finland and Tekes provide opportunities for researchers and research teams to work together with companies within their thematic areas at Strategic Centres in Science Technology and Innovation (SHOK). Two of these these centres, the Finnish Bioeconomy Cluster (FIBIC) and Cluster for Energy and Environment (CLEEN), recently merged to become CLIC Innovation Oy so as to invest in reinforcing research in bioeconomy and clean techology sectors.

2.2.4 Open access test facilities

Open test facilities for research and development of biofuel processes are needed to accelerate the introduction of new technology and innovations. Examples of the Finnish open access biorefinery facilities are shown in Table 15.

Energon, located in Lahti, is a globally unique renewable energy research center. It is an open facility for the private and public sector to perform versatile research and develop solid, liquid and gaseous biofuels, and piloting of new technology. This is facilitated by a large repertoire of boilers and burners.

Bioruukki piloting centre at VTT Technical Research Centre of Finland Ltd is the largest bioeconomy research environment in the Nordic countries, and it combines VTT's expertise in chemistry, energy and biomass handling. Bioruukki is planned to accelerate research and development of processing of biomass from agriculture and forestry and various waste and sidestreams from industry and municipalitiess for the growth of companies. To start with, from March 2015, gasification and pyrolysis research activities will be launched, and expansion into other techniques will take place within the next two years.

BioSampo Training and Research Centre is part of the Kouvola Region Vocational College and is a practical learning environment, which trains hands-on experts and practices experimental research to develop an ethical bioeconomy. The aim of BioSampo Centre is to convert all types of organic waste products and biomass into fuel via the BioSampo process. BioSampo enables local production of sustainable renewable energy and coproduction of electricity, heating and cooling. In addition to local vocational education, BioSampo develops education curricula within the BioSampo satellite school network abroad.

Metener Ltd. Joutsan Ekokaasu offers waste management services in a biogas plant. The biogas is refined into motor fuel and sold in a public filling station in Joutsa. Biomethane production started in spring 2014. Metener has a research laboratory and the company has performed several biogas production trials using different biomass and cooperated with universities and research institutes. Metener has also developed biogas upgrading technology. Joutsan Ekokaasu site is open for visits.

Metener Ltd Kalmari farm is a pioneer biogas producing farm in Finland which is is self-sufficient in electricity, heat and motor fuel. The main feedstock is cattle slurry that is digested in a mesophilic, continuous stirred reactor. Bakery byproducts and occasionally small amounts of energy crops, mainly grass silage, are also digested in the biogas plant. In future, it is also planned to use fat trap and liquid biowaste. Digestate is used as fertilizer in the Kalmari farm. Biogas technology on the Kalmari farm efficiently combines energy production, waste treatment and nutrient recycling. Metener Ltd. is able to run pilot scale tests with different substrates to produce biogas, and provides consultancy and feasibility studies related to biogas production and utilization. The Kalmari farm and Metener Ltd. collaborate with local and international research institutes and development companies. Kalmari farm is open for visits.

Sybimar Ltd. utilizes side streams of the food industry as raw material and manufactures process equipment for production of biofuels. Sybimar has developed a process based on closed circulation, and recycles waste, waste heat, nutrients and carbon dioxide back to energy and food production. The concept can be tailored to serve different needs under local conditions. The pilot plant of the concept, located in Uusikaupunki, includes a fishery, a greenhouse, a biogas plant, a generator as well as a biofuel plant. The fishery, situated on dry land, circulates waste water, which is directed to the greenhouse for use a fertilizer. Gases formed in the landfill are recovered by the biogas plant, and the organic side streams from the greenhouse and the fishery are also directed to the plant. The biogas is used to produce electricity and heat, which are then utilized in the closed circulation concept of Sybimar. The Sybimar closed circulation concept site is open for visits.

Table 15: Infrastructures of relevance for biorefinery technologies and bioeconomy business in Finland

Biorefinery	Location	Biomass used	Volume/Value	Biorefinery/Methodology	Product(s)
1. Open access test facilities					
Energon	Lahti			Energon offers facilities for versatile research of renewable energy and energy efficiency, and also for testing new technology	The Energon research center can be used e.g. for the development of liquid, gas and solid biofuels
Bioruukki	Espoo	Research center can be used f. ex. for biomass from agriculture and forestry, side streams and waste from indutry and municipals	EUR 10 M investment, further EUR 10–15 M will be invested in future	Gasification and pyrolysis research activities and later expanding in to other research areas	
BioSampo Training and Reseach Centre	Anjala, Kouvola	Organic waste, various biomass		Combined heat and power production burning process	Biogas, electricity, heating, cooling.
Metener Ltd, Joutsan Ekokaasu	Joutsa	Local household biowaste and sewage sludge	5,000 tons, waste/y		Biogas refined into traffic fuel
Metener Ltd, Kalmari farm	Leppävesi	Cattle slurry	75 MWh/y electricity, 150 MWh/y heat, 1,000 MWh/y biomethane for traffic fuel	Microbial fermentation; patented biogas upgrading technology	Biogas
Sybimar Ltd	Uusikaupunki			Sybimar's closed circulation concept	Biogas
2. Companies					
Arizona Chemical Oy	Oulu	Crude tall oil from pulp mills	85 employees		Tall oil fatty acids, distilled tall oils, tall oil rosins and pitch
Oulu Waste Manage-ment	Oulu	Sidestreams from Stora Enso pulp mill, including ash/sewage sludge (OPA sediment)			In landscaping activities
Biovakka Finland	Vehmaa, Lapua, Turku	Biodegradable waste (organic waste, municipal treatment plant sludge) and sidestreams	Processing capacity is 75,000–120,000 tons/y with energy efficiency of 4 MW.		Nutrients and biogas for generating electricity and heat
Ekopine Oy	Kajaani	Small-sized wood and sawdust			Biodegradable polymers, ecologically saturated wood
Adven Oy	Kauttua	Collected and processed wood/timber			Energy
FA Forest Oy	Liperi, Viitasaari	Ashes generated by bioenergy processes			Fertilizers
Jyväskylän Energia Oy	Jyväskylä	Ash generated by power plant			Fertilizers
Kumpuniemen Voima Oy	Suolahti	Metsä Wood Suolahti plywood mill sidestreams			Energy
Lohjan Biolämpö Oy	Lohja	Sidestreams from Lohja Laminated veneer lumber Mill			Energy; provides FA Forest with the resulting ash
Green Fuel Nordic Oy	Iisalmi	Sidestreams from Anaika Wood sawmill			Bio-oil
Humuspehtoori Oy	Pälkäne	Wood processing industry co-products (e.g. fibre-rich sludge from Metsä Board Tako mill), sludge and manure from large livestock farms, municipal sludge	Annual capacity ca. 2,000 tons		Soil improvement products, energy
Jepuan Biokaasu Oy	Uusikaarlepyy	Agricultural and industrial sidestreams			Energy, fertilizer products
Kemira Operon Oy	Mänttä-Vilppula	Dried sewage sludge from the tissue paper mill and the city of Mänttä-Vilppula			Energy

Biorefinery	Location	Biomass used	Volume/Value	Biorefinery/Methodology	Product(s)
Kemira Operon Oy	Pori	Sewage sludge from Porin Vesi water company			Surface soil
Metsä Fibre Oy	Joutseno	Secondary heat generated by the pulp mill is utilized in drying excess bark and bio-based sidestreams		Thermochemical gasification	Biofuels
Biokasvu Oy	Tarvasjoki	Sidestreams from agriculture and industry			Organic fertilizers and a range of composting products
Biolinja Oy	Uusikaupunki	Warm and nutrient-rich water from fish farm Services for the management of sidestreams and biowaste in the production of biogas, energy, heat and agricultural nitrate fertilisers. In symbiosis with Sybimar Oy, Uusikaupunki and Vihannes-Laitila Oy, Kalanti			Biogas
Sybimar Oy	Uusikaupunki	Fish-processing byproducts and used vegetable oils		Aquatic biorefinery as a core of the concept	Biodiesel
Biotehdas Oy	Vampula, Kuopio, Oulu, Honkajoki	Biowaste generated by communities, agriculture and industry			Biogas and hygienised fertilizer products
Envor Group Oy	Forssa	Biodegradable waste, paper, cardboard from various providers	Handling of approx. 71,000 tons of different types of bio-degradable waste in 2013		Fertilizers, energy (transport biogas)
Hankkija Oy	Kerava	Mash and yeast from brewing company (Oy Sinebrychoff Ab)	Used 2,000 ton/y yeast		Feed
St1 Biofuels	Vantaa, Lahti, Hamina, Jokioinen, Hämeenlinna (Kajaani in the future)	Unsold bread from HOK-Elanto stores, brewery waste from Oy Hartwall Ab, lignocellulosic residues such as sawdust, municipal biowaste collected by Kiertokapula Oy, biowaste from retail and industries	* (see footnote)		Ethanol, feed (as a byproduct)
Tyynelän maanparannus Oy	Joutseno, Lappeenranta, Imatra, Kotka, Kouvola	Sidestreams (e.g. lime, ash, fibre sludge, other organic waste) from forest industry (Metsä Fibre and Stora Enso)			Fertilizers, soil improvement solutions for use in agriculture, landscaping and organic waste management, seed beds, cover and support materials
Metsäliitto Cooperative, Metsä Wood	Lappeenranta	Sawmill sidestreams, including wood materials such as sawdust, wood chips and bark, which are sold on the open market for use as fuel	Ca 700 tons of ash for manufacturing of fertilizers		Fertilizers
Metsäliitto Cooperative, Metsä Wood	Pöytyä	Sawmill sidestreams, including wood materials such as sawdust, wood chips and bark are sold on the free markets for use as a fuel	Ca 400 tons of fly ash suitable for earthworks per year		
Metsäliitto Cooperative, Metsä Wood	Eskola	Sawmill sidestreams, including wood materials such as sawdust, wood chips and bark are sold on the free markets for use as a fuel			
Punkavoima Oy	Punkaharju	Sidestreams of bark and other wood-based fuels from Punkaharju Laminated veneer lumber and Plywood Mill			Energy
Neste Oil Oyj	Porvoo	Waste and residue-based raw materials (e.g. animal fat from slaughterhouse waste); some of the materials are collected from Finland, but most are imported	Over 400,000 tons/y; total capacity 525,000 tons/y		Diesel

Biorefinery	Location	Biomass used	Volume/Value	Biorefinery/Methodology	Product(s)
Neste Oil Oyj	Naantali (planned biorefinery)	Refining pineoil residues for transport fuel	EUR 3.3 M investment grant from the Finnish ministry of employment and the economy; planned production of 40,000 t bioethanol/y		Transport fuel
Päijät-Hämeen Jätehuolto Oy - Päijät-Häme Waste Disposal Ltd	Lahti	Biological and grease trap waste		Composting	Compost for seed beds; gas generated by the biowaste digestion process is reprocessed into transport fuel
Raisioagro Oy	Raisio	Mill industry byproducts (oat hull flour) from Ravintoraisio Oy	6,000–7,000 tons/y of oat hull flour		Feed
Suomen Megawatti Oy	Kyrö	Mill industry byproducts (oat hull flour) from Ravintoraisio Oy	6,000–7,000 tons/y of oat hull flour		Energy
Veraisen Leipomo Oy	Mynämäki	Veraisen Leipomo deliveres packaged bread after use-by date, leftover food from lunch cafeteria			Bioethanol
Metener Oy	Laukaa	Food industry byproducts (e.g. used beer mash from brewing company Panimoyhtiö Hiisi Oy), biowaste			Biogas (transport fuel)
Metsä Fibre Oy	Kemi	Combustible materials from Metsä Board Kemi mill			Energy
Metsä Fibre Oy	Äänekoski	Planned bioproduct factory using wood-based materials, starting 2017	EUR 1.1 billion investment		Biomaterials, biochemicals, bioenergy, fertilizeres
Metsä Board Oyj	Kaskinen	Metsä Board Kaskinen provides its partners with fly ash			Fertilizers
Metsä Board Oyj	Hämeenkyrö	Metsä Board mill provides an energy production plant with fibre sludge	Ca 24,000 tons of fibre sludge per year		Energy
Äänevoima Oy	Äänekoski	Combustible materials from Metsä Board Äänekoski board mill and Metsä Fibre pulp mill			Energy
Novarbo Oy	Eura	Sidestreams from pulp and paper industry, chicken manure from broiler houses			Fertilizers
Pitkäsen Peruna Oy	Kannus	Pitkäsen Peruna potato processor delivers potato peel mash to livestock farms			Animal feed
A-Rehu Oy	Seinäjoki	Sidestreams generated by the food industry			Feed for domestic animals
Trio Trading Oy	Kokkola	Trio Trading imports Norwegian salmon and produces salmon fillets at the Kokkola fish processing plant. The fish waste is delivered to a local fur farm and a nearby dog food factory			Feed for fur farm, dog food
UPM	Lappeenranta	Crude tall oil	Start-up in 2014: Total UPM investment: EUR 175 M. Annual renewable diesel production: 100,000 tonnes / 120 M litres. Total persons employed: 200, directly and indirectly		Biodiesel
BioA Klusteri Oy/Cursor Oy	Kouvola	Pilot plant (2013–) utilizing pulp and paper mill waste water		Heat from waste water is utilized for algae cultivations, which is then used as feed for biogas production	Biogas, DHA, EPA, fertilizers

Biorefinery	Location	Biomass used	Volume/Value	Biorefinery/Methodology	Product(s)
Sievi Biofuels	Sievi	Planned start-up in 2016. Crop straw including cereals and oil seed plants, green plants from road sides, logging waste	Ca 80 employees Ethanol 50,000 tons, acetic acid 10,000 tons, furfural 23,000 tons, biocoal 172,000 tons, combustible rank 96,000 tons	Formic acid cooking, hydrolysis and fermentation, distillation and absolutation	Ethanol, acetic acid, furfural, biocoal, combustible rank
Green Fuel Nordic Oy	Kuopio (biorefineries will be located in Iisalmi and Savonlinna)	Forest biomass	90,000 tons bio-oil/ year	RTP™ (Rapid Thermal Process)-technology	Bio-oil, bio-ash
Ductor Oy	Helsinki	New technology removes ammonia from organic waste, and therefore enables increased use of cheap, more diverse feedstocks closer to the plant.	15 employees mostly in R&D functions		Patented technology to improve waste management, energy and food production. Biogas and fertilizers
Altia Oy	Ilmajoki (will start in January 2015)	Peel of barleycorn that is a sidestream from the production of ethanol, starch and feed; other biomasses from agricultural fields and forestry.	The plant uses ca. 200 million kg of Finnish barley/y. EUR 1.5 M investment grant from the Finnish ministry of employment and the economy. The total value of the invest-ment was EUR 15 M.		Steam power that Altia Oy will use in the production of ethanol and starch
Forchem Oy	Rauma; The distillation plant is in close connection to the pulp mill from which excess steam is received.	Crude tall oil from forestry, kraft pulping, tall oil fatty acid from crude tall oil distillation.	Production capacity: 48 000 t/year		Tall oil fatty acid, tall oil rosin, distilled tall oil, pitch fuel and speciality blends from the various distillation fractions
Nevalan Peruna Oy	Isojoki	Potato peels, vacuolar fluid from potatoes to be used as fertilizer			Animal feed, compost for soil enrichment, process starch
NSE Biofuels Oy	Varkaus	Forest residues from Stora Enso's Varkaus mill	Demonstration plant, which is a joint venture between Neste Oil and Stora Enso opened in 2009, including a 12 MW gasifier	Gasification	Syngas, which is provided to Stora Enso's lime kiln
Chempolis Ltd.	Oulu		EUR 20 million investment for a biorefinery that commissioned in 2009. Capacity ca. 25,000 t/y of non-wood biomass.	Two patented 3rd generation technologies for biorefining of residual biomasses: 1) Formicobio™ for co-production of non-food cellulosic ethanol, 2) Formicofib™ for co-production of non-wood papermaking fibers, biochemical and biocoal	Biorefinery also functions as a development and marketing centre for testing customer-sourced non-food raw materials and producing sample batches of bioethanol, biochemicals and papermaking fibres
Lahti Energia, Kymijärvi II power plant		Energy-containing waste (solid recovered fuel)	50 MW of electricity, 90 MW of district heat	Gasification	Electricity, district heat
Vaskiluodon Voima Oy	Vaasa	Local biomass, e.g. forest chips and byproducts of the sawmill industry	140 MW output	Gasification	Electricity, heat

Biorefinery	Location	Biomass used	Volume/Value	Biorefinery/Methodology	Product(s)
Suomen Bioetanoli Oy	Kouvola; planned biorefinery	Cereal straw	EUR 150 M investment 20% of which as investment grant from the Finnish ministry of employment and the economy; planned production of 72,000 t bioethanol/y		Bioethanol
BioGTS Ltd.	Laukaa; planned starting at end of 2014	Greasy/oil organic waste from industry and restaurants	1,000 tons of organic waste into ca. 850,000 litres of biodiesel/y	Biodiesel and biogas processes will be based on new technology developed by BioGTS Ltd.	Biodiesel for vehicle fuel and heating oil, and biogas that will be used mainly for heat and electricity production to cover the internal energy demand of the biorefinery plant itself
3. Research institutes					
ABOWE project (ended 9/2014) by Savonia University of Applied Sciences and Finnoflag Oy	Kuopio	Mobile pilot plant was planned and built in Finland for testing enzymatic hydrolysis and microbiological processing of various organic wastes		Raw biomass is pretreated (milling and slurrying) and enzymatic hydrolysis is done by using technology innovated by Finnoflag Oy	Industrial chemicals and liquid biofuels, fertilizers, hydrogen, methane
LignoCat (lignocellulosic fuels by catalytic pyrolysis) -project of Fortum, UPM, Valmet, Tekes (2013–2015)					
Algind	Lahti	Waste waters		Microalgae fermentation in waste waters	DHA, EPA, pigments
Aalto University	Espoo	Polymeric constituents of lignocellulose		Research on new fractionation methods for conversion into high value added products	High value added products
Natural Resources Institute Finland	Helsinki	Biomass from forestry, agriculture and fisheries		Research	
Technical Research Centre of Finland VTT		Various biomasses		Development of technology solutions and innovation services	Food, bioenergy and biofuels, bio-chemicals, and biomaterials as well as bioeconomy-related technologies
Lappeenranta University of Technology		Forest biomass		Development of products achieved through biorefining separation and purification	Products for sugar and sweetener industry
Finnish Environment Institute	Helsinki	Plankton algae		Research	Bioenergy
Oulu University	Oulu	Various biomasses		Research	Biomass conversion and valorization
University of Helsinki	Helsinki	Side-streams from forestry and agriculture, and dairy industry		Research	Biomass conversion and valorization
University of Turku	Turku	Various biomasses		Research	Biomass conversion and valorization (see e.g. Cursor oy)
Tampere University of Technology	Tampere	Industrial waste, biomass-based feedstocks		Research	Biomass conversion and biofuel

Source: *Hamina: Dehydration of hydrous ethanol produced in St1 Biofuels' Etanolix® and Bionolix™ plants and from third party producers. Production capacity of 88 Ml/a of 99.8% bioethanol. Jokioinen: Integrated with the DuPont enzyme production facilities with production capacity of 7 Ml/a bioethanol. Lahti: Integrated with brewery with production capacity of 1 Ml/a bioethanol. Vantaa: Stand alone plant with production capacity of 1 Ml/a bioethanol. Hämeenlinna: Bionolix: Integrated with a biogas plant with production capacity of 1 Ml/a bioethanol.

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2.3 Bioeconomy in Iceland

Prof. Gudmundur Hreggvidsson, Matis, Iceland; Faculty of Life and Environmental Sciences; University of Iceland, Sigrún Elsa Smáradóttir, Matis, Iceland and Dr. Bryndís Björnsdóttir Matis, Iceland. Biorefinery developments in Iceland and relevant technologies

The authors have previously published a survey with a similar content on biotechnology and the bioeconomy in Iceland in the report of Future Opportunities for Bioeconomy in the West Nordic Countries, on behalf of the Nordic Council of Ministers (http://norden.diva-portal.org/smash/record.jsf?pid=diva2%3A791350&dswid=7619).

2.3.1 Introduction

Prospects and potential in biotechnology in Iceland were initially recognized in the early 1980s. Different biotech possibilities were mapped, especially in relation to the fish industry. At the time it was recognized that biotechnological solutions applied to the fish industry could lead to greater economic return by enabling fuller exploitation of raw materials and providing improved and more efficient process technologies. It was also recognized that biotechnological tools and processes could be used to turn fish rest materials into high value products. Biotechnology was seen as capable of solving emerging problems connected with waste generation and accumulation. The genetic resources found in extreme biotopes of Iceland were also recognised as having possibilities for providing valuable tools, enzymes and microbes for industrial applications or for use in research. These views and directions are still fundamental to biotech in Iceland and are currently crystalized in the concept of the biorefinery in a biobased economy context.

The current emphasis in Iceland is still on regional bioresources and genetic resources unique or particular to the region, which has led to common strategy setting, innovation and collaborative research projects with the other Nordic countries and more specifically within the West Nordic Region. In the West Nordic area collaboration includes bioeconomy issues and common interests in developing the blue bioeconomy in Iceland, Faroe Islands and Greenland.

Icelandic biotech research has so far mostly been within research institutes and a receptive industrial environment has been lacking. This is changing fast, and relatively recent collaborative efforts of research institutes and industry has resulted in a number of new processes and commercialized products. Education and research infrastructure is already at a high level and abundant underexploited bioresources and unique genetic resources are present in the country. General R&D activities, some of which can be traced back to the early pioneering steps in the 1980s and 1990s, have generated results suggesting the direction with the most promising potential. This will be used as guidance for future development

An integrated biorefinery can be defined as a biobased production platform that encompases the whole technological chain for processing raw biomass to highly processed value added products. It is capable of processing multiple feedstocks, deploys a range of technologies including mechanical, physicochemical and enzymatic preprocessing and fractionation techniques and further chemical, enzymatic or microbial conversion refinery techniques for product generation. Such a platform aims at complete utilization of the biomass feedstocks, and products for various markets can be taken out at different steps of the process in different volumes and of different values. There are usually a range of product streams such as feed and food components, platform chemicals, speciality chemicals and different energy carriers (biofuels). Waste materials are used in biogas production or as a fertilizer. As strictly defined there are no integrated biorefinery platforms in Iceland, but they exist in part and have some unique local features.

In addition alternative bioresources to fish factory rest biomass are being investigated. The biorefinery platforms being established or considered in Iceland are necessarily based on biomass availability and most would be considered blue biotechnology based. However, the development is also influenced by access to abundant and relatively low-priced energy, such as for the microalgae platform. Potential biorefinery platforms considered important in an Icelandic context and classified by the rainbow scheme of biotechnology include the following:

The classification is based on the source of biomass

- Fish industry rest raw material biorefinery platform, (Waste) Blue Biotechnology.
- The macroalgal biorefinery platform, Blue Biotechnology.
- The microalgae biorefinery platforms, Blue/Yellow Biotechnology.
- Crop plant platform, Green Biotechnology.
- Waste materials biorefinery platform, Green/Blue/Grey Biotechnology.

2.3.2 *The two most important bioresources in Iceland as feedstock for future and current biorefineries*

In Iceland, the two most important bioresources for biorefineries are rest materials from fish industries and macroalgae.

Rest material platform from the Fish industry (Blue Biotech)

Various projects are ongoing that aim at increasing resource efficiency in the fish processing industry by adopting process biotechnology. In most instances this involves development of enzymatic processes to increase efficiency, improve quality and generate new food products from fish and thereby add value. Fish biomass is an important proteinaceous food resource, and therefore is not, as such, typical or even desirable as a biorefinery feedstock resource. However, bioconversion techniques can be used to produce alternative more valuable non-food products. Also, rest raw biomaterial from the fish industry that otherwise would have gone to waste can be considered as a potential biorefinery feedstock to be converted to added value products. Today, approximately 2,000–3,000 tonnes are used in landfills per year. Potential products that can be generated are valuable non-food biomolecules or compounds, such as enzymes, amino acids, peptides and oligosaccharides for the food supplements and healthcare markets or the chemical and biotech industries.

Research into enzyme aided processes and products for the fish industry started in the late 1980s in the University of Iceland, the Fishery Research Institute and IceTech (Technological Institute of Iceland). Amongst other things, this included cold active processing enzymes for generation of food flavorants from fishery wastes, membrane removal from fish tissues, oligosaccharides from shrimp shell waste, thermophilic enzymes as process aids in fish meal production, and industrial enzymes from cod intestinal waste. Bioprospecting of enzymes from cold adapted biotopes is also increasing, especially from marine microbes living in coastal areas. *Matis* has invested a major effort in this field especially to target enzymatic activities for processing and developing marine polysaccharides and derivatives as novel substrates and products for industry, and as bulk feedstock biomass for emerging marine biorefineries. Cold active enzymes also have high potential in food industries where high temperature is detrimental. The Icelandic company *Zymetech* has explored various possibilities for such applications focusing on proteases from cod.

The biotechnological processes or process aids help ensure near complete utilization of the fish catch. The processes may be integrated into existing technology chains of the fish processing plants or into associated independent product lines, often in small companies. This is an industry-driven development that aims at increasing resource efficiency in the industry. Between 10 and 20 companies base their product lines largely or partly on biotechnological solutions and use rest raw materials from fish processing. Many of these companies are associated with larger companies that harvest and process the fish, which is important for their success. To illustrate the scope and breadth of activities a few examples are given below.

Chitin and derivatives

Carbohydrate-rich shrimp shells as feedstock is an example of a very successful use of rest biomass from the "fish" industry for a specialized biorefinery platform.

Primex founded in 1999 (http://www.primex.is/) is a company located in Siglufjordur in the North of Iceland that manufactures quality chitin and chitosan from shrimp shells. The company uses physicochemical refinery methods for producing different grades. Primex has collaborated with Matís and the Icelandic Universities. Primex supplies products in bulk internationally to local distributers for nutritional, cosmetic, food and biomedical applications and also derived health promoting products for local Icelandic markets.

Genis (http://www.genis.is/) is located in Siglufjordur in North of Iceland. The business model is based on applied research that goes back to work carried out at IceTech in the 1990s. The feedstock biomaterial is chitin that is processed further by Genis using a combination of physicochemical and enzymatic refinery methods. Genis actively pursues innovative research with a laboratory located in Reykjavik that has led to development of high added value bioactive chitooligosaccharide products for health and medical use. In order to lower overall production costs, Genis in collaboration with Matis and the University of Stuttgart has developed advanced enzyme technology and an associated fermentation facility for producing processing enzymes at the site. Markets targeted are the food supplement, health and medical sectors.

Fish innards

A few companies use fish innards as raw material for their products and numerous possibilities exist in expanding product range from these rest materials using different.

LYSI was founded in 1936 and produces refined fish oils for human consumption. It utilizes fish liver as a raw biomaterial for production of a range of health promoting fish oil products. LYSI uses advanced physicochemical refinery methodologies in their production lines and places strong emphasis on research and product development. It collaborates with leading international pharmaceutical firms and research organizations and nationally with the University of Iceland and Matis on a continuous basis. LYSI supplies consumer markets and also provides bulk products internationally to local distributers. www.lysi.com/

Zymetech was established in 1999 as a start-up from the University of Iceland based on even earlier research, started in the eighties. The raw biomaterial used are fish innards (gut: pyloric caeca). Zymetech specializes in research with own facility and molecular biology and enzymology expertise and has strong collaborative ties with the University of Iceland. Zymetech develops and manufactures enzymes from cod innards and formulations for the health and cosmetic industries worldwide (http://www.zymetech.com/).

Aegir Seafood was founded in 1995 and produces canned cod liver for human consumption. In 2008 the company adopted enzyme technology for improving efficiency and quality of the product. The process was developed in collaboration with Matis in 2007. Aegir seafood is not a biorefinery as such, but it is included to show alternative biotechnology aided utilization of the same material. Among customers are large supermarket chains, gourmet markets and premium foods providers world-wide (www.aegirseafood.is/).

Fish skin, bone/cartilage and offcuts

Today most of rest material from fish processing goes to fish meal factories. Besides offal this includes fish skin, bones and offcuts. Fractionation of this material into separate components allows specialized processing. Fish skin, for example, is a very distinctive tissue biochemically and structurally and has been recognized as a valuable rest raw material for a range of added value products. Higher value products can also be derived from flesh offcuts and fish bones.

Kerecis was established as a medical device/biotech company in 2009 (www.kerecis.com/) and processes cod skin using a proprietary method that preserves its structure and lipid composition. The acellular fish skin is used for tissue regeneration by transplantation. Applications include reconstructing the skin in chronic wounds, for hernia repair, breast reconstruction and dura-reconstruction.

Atlantic Leather is an Icelandic tannery founded in 1994 (www.atlanticleather.is/), which manufactures fish skin leather from salmon, perch, wolfish and cod. Atlantic Leather uses proprietary physicochemical tanning methods. The company successfully targets the international fashion industry.

Codland was founded in 2012 (http://codland.is/) and aims to maximize resource efficiency in the fish industry. Codland has established a platform for product development and value creation using rest raw materials, fish skin, and offal and fish bones from the fish processing industry as feedstock. Their current main product is a collagen preparation from cod skin by physicochemical and enzymatic methods, but they also produce mineral supplements from fish bones and oils and fish meal from fish processing discards. Codland collaborates with Matis in product development in both national and international projects.

Iceprotein was founded in 2005 (www.iceprotein.is/) by Matis and is now owned by FISK Seafood. It is situated in Saudarkrokur in the North of Iceland. Iceprotein produces bioactive peptides from proteins in fisheries offcuts by a combination of physicochemical and enzymatic methods (www.iceprotein.is/).

The macroalgal platform

There is an immediate interest in Iceland in seaweed biomass resources available in coastal areas and the possibility of extensive offshore cultivation. Coastal seaweed biomass production is vast in the fjord, Breidafjordur. The coastal seaweed amounts to 1 million tonnes of which 50% can be harvested, and even more seaweed biomass is produced further out in the sea by larger sized kelp species. Coastal areas can be harvested every third year, but seaweed can also be cultivated and produced in high abundance. Macroalgae surpass other biomass of comparable bulk and in ease of cultivation. They accumulate high levels of carbohydrates, the component that is a potential bulk feedstock for chemical, enzymatic and microbial bioconversion to added value products, including biofuels and platform chemicals. Conditions for establishing an economic seaweed biorefinery platform in Iceland are favourable; energy cost for example is relatively low and use of available geothermal heat and steam enables efficient preprocessing of the biomass and facilitates subsequent fractionation and enzymatic access to polysaccharides. Harvesting and preprocessing technologies have already been established in Iceland.

Thorverk (http://www.thorverk.is/): The company harvests coastal seaweed in the fjord, Breidafjordur, for production of dry seaweed meal and uses geothermal heat in its drying processes. Until very recently, no processing of high value compounds from seaweed has been available and more than 95% of the seaweed meal produced is exported.

Marinox (http://www.unaskincare.com/en/story/company/): The company was founded in 2011 and is based on years of extensive work done in collaboration with Matis. It is a pioneer in Iceland in the processing and utilization of high value compounds from macroalgae. Marinox has developed several proprietary processes to extract highly active polyphenols and sugars from Icelandic seaweed, and has already commercialized several skincare products (UNA skincare) containing these extracts.

Taramar (http://www.taramar.is) is a recent startup company that specializes in developing and producing pure bioactive skincare products from marine bioresources and medical herbs.

The recalcitrance of polysaccharides is the main obstacle to bulk utilization of seaweeds in biorefineries. The main constituent polysaccharides are often polyuronates or complex, heterogeneous polymers containing different, often sulphated, sugars, including deoxy sugars and sugar acids (uronates). It is difficult to degrade these polysaccharides into monosugars by physicochemical methods and fermentative organisms are also lacking to convert the monosugars further to added value products. Important work is ongoing at Matis in utilizing unique Icelandic microbial resources for solving these problems for brown algae polysaccharides. Matis has developed specific thermophilic enzymes for complete degradation of these polysaccharides and is working on developing an efficient thermophilic bioconversion organism by metabolic engineering.

Macroalgae as a potential industrial resource has been recognized in Iceland. Numerous projects are in progress, from cultivation to development of very specific value added products. The potential of macroalgae is high. It is a source of new sugars, such as appreciable amounts of so called rare sugars, for industry. It is also a source of highly bioactive small molecules, including oligosaccharides, polyphenols, flavorants and colorants. The greatest potential is, however, bulk utilization in multi-value stream biorefineries, but progress in this direction is dependent in enzymatic and fermentation technologies.

Other biomass resources

Lignocellulosic biomass (wood and terrestrial plants) is limited in Iceland as a sustainable feedstock for biorefineries. There is, however, ongoing national effort in forestry and substantial land is available for fast growing special feedstock plants.

Waste materials biorefinery platform: Oilaceous raw material from the catering industry (available quantity 500–600 tonnes) and fat waste material from slaughterhouses is collected from all over the country and processed to biodiesel by the company Orkey in Akureyri. Future prospects may lie in cultivation of Oilaceous crop plants.

It is calculated that about 18,000 tonnes of organic household waste accumulates per year in Iceland. Biogas generation from municipal waste has already been implemented in the larger population centres but collection of organic waste could possibly be extended to cover rural areas. This is also an environmental issue because garbage collection and recycling following current regulations and directives is costly for small communities.

2.3.3 Research

Universities: Four universities carry out research and provide education in biosciences and associated disciplines. The University of Iceland, the oldest university in Iceland, has a strong, diversified research and education portfolio and covers the greatest range of subjects. It is particularly strong in food sciences, molecular biology, genetics and related engineering subjects. Several biotechnology start-up companies have emerged out of biochemical and molecular biology research carried out in the Schools of Engineering and Natural Sciences and the School of Health Sciences. The university is also involved in several innovation related projects with local and/or international partners. More specialized studies are offered in the younger universities: the University of Akureyri provides undergraduate education in blue biotechnology and microbiological biotechnology; and the University of Reykjavik provides basic and graduate studies in health and biotech-related engineering. The Agricultural University of Iceland provides education related to farming and in management of agricultural bioresources and waste. Research and development in these universities covers both applied and basic research aspects, with greater emphasis on the latter.

The number of undergraduate students in biosciences is relatively high. The large majority of students who gain B.Sc degress pursue postgraduate studies in the medical field and related disciplines and subsequently seek carreers in that sector. This is not expected to change until biotech industry has noticeably taken off in Iceland. The medical research sector is quite strong in Iceland with Decode genetics, the University Hospital and strong independent medical research institutions in heart disease and cancer research.

Research institutions

Matis (www.matis.is) plays a central and important role in applied biotech research in Iceland. It is a government owned, independent research company, founded in 2007 following the merger of three former public research institutes and the private biotech company Prokaria. It has its roots in food science and resource management as well as having traditionally a strong connection to the industry. Matis has strong relationships with the University of Iceland, especially with the Faculty of Food Science and Nutrition, but also with the Faculties of Life and Environmental Sciences and Engineering. Many of the lead scientists in Matis hold positions and teach specialized subjects in the University of Iceland. A number of students pursue second degrees in diverse research and development projects that Matis conducts in diverse fields such as biotechnology, food sciences, engineering, and environmental and bioresource monitoring. Matis is aligned to the food and biotechnology industries as well as providing Iceland's leading analytical testing service for public and private authorities.

Matis also specializes in bioprospecting of the unique extremophilic biotopes in Iceland for enzymes and microbes as well as for small bioactive molecules from microbes, and marine fauna and flora of Iceland. In collaboration with industry Matis develops formulations of natural ingredients for cosmetics and food & feed supplement markets.

Matis is very strong in developing enzymatic and microbial biorefinery tools including carbohydrate active enzymes for degrading natural carbohydrate polymers and in engineering microorganisms of high potential for conversion of biomass to added value products in biorefineries.

Matis provides research facilities for small companies and has state of the art laboratories for R&D biotech research. The staff is versatile, highly skilled and experienced, which is reflected in participation in a large number of successful international projects and peer reviewed scientific papers. Matis actively pursues research and development in food-related and industrial biotech as was the case previously in the institutes that merged to form Matis. Matis has initiated research and collaborated with industry in many successful national projects that have led to new or improved processes or new commercial products.

Rural research centres exist around the country with strong connections with authorities, institutions, businesses and individuals in the surrounding areas. They are of great importance for the development of the biotech industry as they provide research facilities and experts for investigating, monitoring and mapping local bioresources and for supporting innovative development of local resources. Seven research centres belong to the University of Iceland and another ten small stations specializing in food science and biotechnology services are run by Matis. Of special importance for biotech is the Matis biotechnology centre in Saudarkrokur, with a state-of-the-art research laboratory in proteomics and research into bioactive natural small molecules, and pilot plant facilities for biorefinery processing of rest material from the fish industry and other bioresources.

Another small important rural biotech research facility is *BioPol* established in 2007 and located in Skagaströnd in the Northwest of Iceland. It specializes in biotechnology research and supports innovations in the area in the field of marine biotechnology. BioPol is a private research company owned by the University of Akureyri and the Skagaströnd municipality.

Companies

The level of education among employees and R&D competence in Icelandic biotech companies is comparatively high. While many of the business ideas originate from innovative research in Universities and Research Institutes in Iceland, further development and research directions are usually pursued within the companies. Even if small, they keep laboratories and specialized staff, and many actively collaborate with universities and research institutes. If opportunities arise, they participate in international Nordic or European research projects. Funding from both international and national sources is of great importance for continued research and product development in the companies.

Currently numerous different biorefinery opportunities are being pursued in Iceland using different bioresources and approaches. Marine bioresources and blue biotechnology is obviously important for Iceland, but the range is surprisingly broad, with blue, green, yellow, brown and grey biotechnologies overlapping in various ways. Companies exist that specialise in bioenergy, molecular farming, enzyme formulations, medical aids, health supplements and cosmetics. The companies as production platforms, however, usually do not cover a complete technological chain of a biorefinery. Some are at the harvesting and preprocessing end. They produce and market low value, high volume primary bulk products for further processing elsewhere, such as milled and dried seaweed meal and chitosan polysaccharides derived from shrimp shells. Others start from already preprocessed biomaterials (e.g. chitin), which is processed further to marketable higher added value end-products for consumer or specialized markets. The feedstock and products generated are usually of a narrow range but the products may be of high value and unique.

Funding, Investments and Future prospects

Biotech/biorefinery development in Iceland is more industry-driven than the result of government directives, and the Icelandic biotech field still benefits from relatively high private investments around the turn of the century, such as in PROKARIA that merged with Matis and companies that are active in the market today, such as Zymetech, ORF and Genis. Government funding has increased substantially in the recent years, but there is fierce competition for it and as a result the funding is thinly distributed across a number of very different fields of research (e.g. The Icelandic Research Fund). International funding received through the EU and Nordic collaboration has been of primary importance for development in the biotech field in recent years.

Official policies could definitely be sharpened. The research environment infrastructure is relatively strong for biotech/biorefinery development, but national financing may not be focused or sufficiently long-term. Current R&D policies apparently emphasise short-term product development (Technology Development Fund), and funding for advanced biotech is haphazard and a long-term vision in a bioeconomy context is unclear. The bioeconomy emphasis of the Icelandic government as realized, for example, in the Icelandic chairmanship project "NordBio" 2014–2016, is highly encouraging. The results from this project "Test Centres for Green Energy Solutions – Biorefineries and Business Needs" will be used to select innovation projects under the "NordBio" program for the final year of the program.

Further, the Nordic Council of Ministers and Nordic institutes have supported regional bioeconomy projects in the West Nordic region, focusing on Iceland, Greenland and the Faroe Islands. These efforts have proven very important in providing an overview of the bioeconomy in the region, identifying opportunities and presenting an action plan for the region (see the final report of the project Arctic Bioeconomy: http://bit.ly/bioeconomy-wn).

The action plan is currently being implemented because funding has been secured for the recommended follow-up project "Arctic bioeconomy II-Biotech" as well as the "Blue Bioeconomy" project which the Faroe Islands are leading under the Danish chairmanship program (2015–2017). In addition, applications are currently being made for the "West Nordic bioeconomy panel" and for the "Centre of Excellence in Arctic Research", focusing on biotechnology as a driver for change. All these efforts aim at making innovation and development in the West Nordic bioeconomy more focused and effective.

Earmarking or targeting a part of available governmental funding for bioeconomy and biorefinery development would make a large difference in the right direction. To some extent this has been done regarding marine bioresources. A dedicated fund, The Fisheries' Research Fund (AVS), which supports different aspects of applied marine research, has been fundamental in establishing a fruitful interplay between the marine industry and the research sector. This collaboration has been demonstrated in the marketing of new products and in new industrial biotech processes in recent years.

2.3.4 Status and prospects

The status and prospects for biorefinery utilization is different for the different potential bioresource feedstock.

Fish industry rest raw material platform
Currently, there is a surge in research activities and subsequent industrialization in fish factory-related blue biotechnology that aims at complete exploitation of resources, especially fish rest raw materials. It is clear that funding by AVS and the Technical Development Fund has been an important factor in furthering this development, launching new projects and securing the necessary interaction between research institute and industry. The Fish industry is also becoming more responsive to biotechnological process solutions than was the case only decade ago and investment in fish processing biotech is growing fast.

The macroalgae platform is very much less advanced on an industrial basis than the fish industry biorefinery platform. One company in Iceland specializes in harvesting and processing seaweed in bulk. It produces dry milled seaweed where geothermal heat is used in the drying process. Almost the entire product is exported for further processing by the mother company. A small number of companies in Iceland utilize biological components of seaweed biomass in consumer products targeted at food, food supplement and cosmetic markets.

Seaweed biomass has considerable potential as feedstock for multistream integrated biorefinery processes because seasweed is highly productive and contains up to 60% carbohydrates. However, the constituent polysaccharides, such as alginate in Brown algae, are quite resistant to physicochemical degradation to monosugars that furthermore are not fermentable by traditional organisms. This has limited progress. Important work is ongoing at MATIS on developing thermophilically robust biorefinery enzymes and organisms for conversion of seaweed biomass to added-value bulk platform chemicals, biofuels and speciality chemicals. Matis participates in a number of Nordic and European projects in the field.

Several start-up companies based on processing of seaweed raw materials have been established in countries with shorelines in the north Atlantic region and/or where there are possibilities for offshore seaweed cultivation. These include the Faroe Islands, Denmark, Norway, Ireland, Scotland, France, Netherlands and Portugal. In Iceland this is also evidenced by recent queries from abroad about access to Icelandic seaweed resources in part motivated by an interest in the favourable conditions, low energy costs and cheap and abundant hot water for processing. The early harvesting and preprocessing part of the value chain is relatively low tech, high bulk and low value. Therefore, in order to make most of this bioresource in Iceland, steps need be taken to develop downstream high tech bioconversion processes for manufacture of more specialized higher value bulk products. There is definitely an Icelandic industrial interest for this bioresource in different parts of the country and pioneering work has been initiated, especially in the West of Iceland around the fjord Breidafjördur.

The microalgal platform. The relatively low energy costs have kindled interest in Iceland in the microalgae biorefinery platform. Traditionally, microalgae and cyanobacteria are grown in open air ponds to obtain single cell protein used for animal or human consumption, but mass production of single-celled algae in large cultivation vessels is gaining ground. A number of potential high added value products have been identified that can be produced by these organisms, such as omega-3 (EPA/DHA) fatty acids, health promoting glucans, fucoxanthan, lutein and biodiesel. Basically, feed requirements are only CO2, exogenous sources of nitrogen and phosphor and light, but abundant energy is needed.

The main driver for this development is the potential for low cost cultivation of microalgae due to low priced energy in Iceland. Additional supportive factors are the proximity and recycling of wastes from aquaculture, greenhouses and the fish industry and the availability of abundant cheap geothermal hot water and carbon dioxide from geothermal power plants. A number of industrial initiatives are ongoing and this is of interest to rural municipalities and companies in aquaculture as an opportunity to recycle waste and produce feed. This is an industry-led development which is still at an early stage.

Crop plant product platforms. This is a large unexplored field in Iceland. It covers a heterogeneous field that includes molecular farming, harvesting particular wild plants or cultivation of plants for production of special non-food components, oil-containing plants for biodiesel production or just lignocellulose sugars for feeding integrated multistream biorefineries. In Iceland opportunities exist both for cultivating fast growing plants (e.g. salix species) for general biomass feedstock production or a particular plant as feedstock for specialized biorefineries. Land is abundant and large areas are not suitable for traditional agriculture. Another resource for such production, which may be scarce in other countries and/or be highy in demand for agriculture, is the abundant water found in Iceland. A number of small companies harvest wild flora for particular components to use in cosmetic, nutraceutical or health promoting creams, ointments, tinctures and extracts, such as *SagaMedia* (http://www.sagamedica.com/) that utilizes Angelica, and Natura Islandica (http://fjallagros.is/en/) that harvests wild Icelandic moss (lichen). In many instances these plants can be cultivated in a larger scale.

Other and possibly more lucrative possibilities may be in greenhouse production of particular production plants for molecular farming for example, due to low energy cost. This has taken off in Iceland in a very promising way.

ORF ltd (http://www.orfgenetics.com/) and its daughter company *Sif*, is a highly successful Icelandic biotech company, which pioneered the manufacturing of growth factors and other recombinant proteins in barley. The recombinant barley is cultivated in geothermally heated greenhouses, bypassing the use of bacterial or animal cell production systems.

Waste materials platform. This platform consists of miscellaneous activities based in most cases very specialized feedstocks of waste and/or fish rest raw material.

Garbage and municipal waste is currently used for production of biogas which is dependent on availability of large volumes of the waste. Only Reykjavik and Akureyri produce garbage waste at an appropriate scale for methane production. In Reykjavik methane is currently processed at Alfsnes municipal waste landfill site in Reykjavik by *Metan hf.* (http://www.metan.is/). Approximately 80% of the gas produced at Alfsnes is collected and used as fuel. *Nordurorka hf.* (http://www.no.is) produces methane in Akureyri from municipal waste. Utilization of municipal waste biomass for energy production is an economically feasible process and its utilization is important for environmental reasons. However, the biogas production only meets a fraction of the total energy demand for transport in Iceland.

SORPA (http://www.sorpa.is/en), a waste management company in Reykjavik, has recently established a biogas research facility to study the biological processes in biogas production. The ongoing research aims at more efficient production of methane from municipal waste where the parameters under study include type of organic materials, pre-treatment methods, temperatures range, etc. The company collaborates in national and international projects in minimizing environmental impact and increasing gas output and efficiency of methane production. The feasibility of production of biogas from livestock manure as an alternative-sustainable and economic energy source for farms has been recognised in Iceland, and initial steps have been taken in developing small biogas production plants using manure.

Orkey (http://orkey.is/) in Akureyri uses frying oils from restaurants and animal fat from slaughterhouse waste from the whole of Iceland for the production of biodiesel. In the process the waste is reacted with methanol generated from geothermal gasses by the company Carbon Recycling.

Prokatin (http://www.prokatin.is/) has invested in a pilot scale facility the use of geothermal gasses H2S, CO2 and H2 for production of single cell protein and sulphur.

Fish industry platform. Matis traditionally plays a central role in innovative engineering for the fish industry and biotech in general and is in the forefront of developing biorefinery applications and solutions for side stream and fish rest material utilization in Iceland. Matis is also closely connected to the food science and engineering faculties of the University of Iceland which have had a long strong supportive role in research and development for the more traditional fish processing platforms. A number of process solutions generated by this research and collaboration have been incorporated into product lines of established fish factories and others have served as a basis for establishing specialized companies. Matis provides facilities and both lab- and pilot scale equipment for supportive and innovative research and development within the fish industry sector. Of special importance is the pilot scale facility in Saudarkrokur in the North of Iceland. This facility offers research lab space as well as processing facilities to develop ideas to pilot scale-up phase, where scientists and biotechnology entrepreneurs can develop their products and processes in cooperation with scientists and specialists at Matis. Equipment at the centre includes bioreactors of various sizes, spray driers, ultra-centrifuges etc.

Specialized research or engineering equipment relevant for biorefinery technologies Iceland

Established biotech companies in Iceland necessarily have relevant technological platforms that they need for their production. The platforms can be very specialized for a particular production and are often valuable and protected property of the companies involved. The equipment can vary enormously and be based on mechanical, physicochemical or biotechnological approaches or a combination thereof. The equipment or facilities range from bioreactors for enzymatic or chemical processes (IceProtein, Genis, Primex), fermentation equipment for producing biorefinery enzymatic tools (Genis) at the production site, associated down processing and recovery equipment such as ultracentrifuges, spray driers, and large scale enzyme purification stations (Genis, Matis, ORF, Zymetech), and even specialized greenhouses for molecular farming (ORF).

Examples of companies established from work initially carried out in in research institutes and universities

Marel: Originating from research at the University of Iceland. An international equipment provider for the fish industry and other food production sectors.

IceProtein: Originating from research at Matis. A small company in the North of Iceland that produces bioactive peptides from fish offcuts and offal side streams of fish factories.

Zymetech: Originating from research at the University of Iceland specializes in cold active enzymes from fish for different formulations for the health and cosmetic markets.

Genis: Originating from research at IceTech (Technological Institute of Iceland) produces high added value oligosaccharides from chitin using enzyme technology.

Carbohydrate rich seaweed can be defined as a second generation biomass of high potential for an integrated biorefinery, where harvesting and preprocessing is performed first and then bioconversion, enzymatic or microbial (or chemical) processes for generation of added value products of various types. Today most of the technology chain for high volume biorefinery processing to bulk value added products is lacking in Iceland. One company, Thorverk, has a harvesting and primary preprocessing platform for producing seaweed meal. An important feature of the process is the use of geothermal hot water for dewatering and drying of the product.

A number of companies are being established for microalgal-based production of various products using large scale photobioreactors and associated downstream product recovery technologies depending on product. The technology is imported in most cases and may differ from one company to another and only few have started commercialization of their products.

The geothermal spa company, *Blue Lagoon* (http://www.bluelagoon.com/about-us/research-and-development), fractionates components from geothermal cyanobacteria for use in their cosmetic and health promoting creams and ointments.

The company *Algalif* (http://www.algalif.com) in the Southwest of Iceland has recently been established for production of axtasanthin from microalgae. Research facilities, equipment, including photobioreactors, and supportive expertise is available at Matis, BioPol and the University of Akureyri, and to some extent locally in small research centres.

Advanced technologies and expertise relevant for improved biorefineries

Processing technologies in the fish industry: Iceland is in the forefront in developing technologies for complete utilization of fish harvests in general, and more specifically for utilizing or recycling rest raw material from the fish industry in a biorefinery context. This includes employing various methodologies such as biotechnology and integrating those with traditional fish plant processes. Necessarily many different actors and experts are needed to bring the idea from laboratory to market; from a small to a full scale process.

Molecular Biology: Expertise in molecular biology is at a high level in the country. Advanced work is carried out in the universites in various biotech and biorefinery-related basic research. Matis leads the applied research in this field in Iceland, and has the infrastructure, equipment and range of expertise needed for a necessary holistic approach.

Sequence based bioprospecting technologies R&D in thermophilic enzymes – metagenomics and genomics: At Matis the same research group has been working in this field of enzyme bioprospecting from extremophilic biotopes of Iceland from the late 1980s. This has ensured important continuity of the R&D work in the field, and the group is internationally well-known in this field, participating in a number of international projects. Matis has large proprietary microbe and enzyme collections, and enzymes have been developed and commercialized by the Matis group for molecular biology applications and for the chemical and the food industries, especially the carbohydrate industries. Commercialization has been aimed at foreign markets, mostly through R&D contracts made with large industrial companies including Roche, Nestle, Roquette Frères, Wacher Chemie and SudChemie. Since the merger to form Matis, there is an increased emphasis on processing enzymes for Icelandic bioresources, and commercialization effort has been strengthened by direct marketing through a small daughter company, PROKAZYME.

Metabolic engineering of extremophiles: Matis is one of few research institutes working on metabolic engineering of thermophiles, which have high potential as robust biorefinery organisms for consolidated biorefinery processes utilizing a wide range of sugars. Thermophiles are optimal for the harsh conditions encountered in industrial feedstock slurries.

Important work on application of fermentative organisms in a biorefinery process is also carried out in the University of Akureyri through the development of fermentative thermophilic biorefinery organisms.

Table 16: Open Access Test Facilities in Iceland

Biorefinery	Location	Biomass Used	Biorefinery Methodology	Products
Matis	Reykjavik with research stations around the country	Various	Biorefinery processes; mechanical, physicochemical and biological. Bioprospecting, biorefinery enzymes; biomolecules. Product development. Metabolic engineering of biorefinery organisms. Food and biomass processing.	
Biotechnology centre in Saudarkrokur (Matis)	Saudarkrokur; North of Iceland	Marine bioresources	Marine biotechnology and pilot processing of rest raw materials from fisheries	
Innovation Centre Iceland	Keldnaholt	Various	Physicoehmical processing of biomass	

Table 17: Companies with private infrastructure of relevance for biorefinery technologies

Biorefinery	Location	Biomass Used	Biorefinery Methodology	Products
Matis	Reykjavik with research stations around the country	Various	R&D in biorefinery processes, mechanical physicochemical and biological; Bioprospecting, biorefinery enzymes; biomolecules; Metabolic engineering of biorefinery organisms	Product development from various bioresources. Tools for biorefineries: Enzymes and biorefinery organisms
Biopol	Skagaströnd North of Iceland	Marine bioresources	Specializes in biotechnology research and supports innovations in the field of marine biotechnology	Product development from marine bioresources
Prokazyme	Reyjavik	Thermophilic bacteria	Enzyme provider – strategic partner of Matis, and some European Universities	Enzymes for carbohydrate industries, biorefineries and molecular biology
Sorpa	Household waste	Household waste biodegradable waste	Mechanical and physicochemical refining	Various product development including methane
Nordurorka	Household waste	Household waste biodegradable waste	Mechanical and physicochemical refining	Methane
Mannvit	Reykjavik, Akureyri	Waste materials, rest raw materials	Engineering: Rest raw material utilization and renewable energy, including biofuels	Pilot and full scale process lines
Primex	Siglufjördur, North of Iceland	Waste shrimp shells from shrimp processing plants	Engineering, renewable energy including biofuels	Chitin and chitosan polysaccharides

Biorefinery	Location	Biomass Used	Biorefinery Methodology	Products
Genis	Siglufjördur, North of Iceland	Chitin	Physicochemical and enzymatic refining	Bioactive oligosaccharides
Codland	Grindavík, Southwest	Offal, bone and fish skin	Physicochemical and enzymatic refining	Collagen, peptides, minerals and fish oils
IceProtein	Saudarkrokur North of Iceland	Fish offcuts	Physicochemical and enzymatic refining	Peptides
Lýsi	Reykjavik	Fish offal	Physicochemical refining	Liver oils and derivatives
Grýta	Blönduós, North of Iceland	Fish rest materials	Physicochemical and enzymatic refining	Flavour compounds
NorthTaste	Höfn í Hornafirði	Fish rest materials	Physicochemical and enzymatic refining	Taste
Kerecis	Isafjördur/ Reykjavik	Fish skin	Physicochemical refining	Fish Skin Transplants
Thorverk	Breidafjördur, West of Iceland	Seaweed	Mechanical and physicochemical refining	Flavour compounds
Marinox	Reykjavik	Seaweed	Physicochemical refining	Bioactive small molecules and oligosaccharides for skin care products
Algalif	Keflavik	Microalgae	Fermentation and physicochemical refining	Microalgae components e.g. astaxanthin for the nutraceutical, cosmetic and pharmaceutical industries
Blue Lagoon	Grindavik	Microalgae	Fermentation and physicochemical refining	Microalgae components, cosmetics and skincare
KeyNatura	Reykjavik	Microalgae	Fermentation and physicochemical refining	Under development
Vistvæn Orka	Reykjavik	Microalgae	Fermentation and physicochemical refining	Under development
Matorka	Grindavik	Microagae	Fermentation and physicochemical refining	Under development
Saga Medica	Akranes, South West of Iceland	Angelica	Physicochemical refining	Bioactive small molecules in formulations for the health care market
ORF	Reykjavik/ Grindavík	Barley	Molecular farming in barley	Growth factors and enzymes
Natura Islandica	Reykjavik/ Akranes	Icelandic moss (lichen)	Physicochemical refining	Various products: tinctures, creams and powders
Orkey	Akureyri	Catering and slaughter house waste	Physicochemical refining	Biodiesel

Biorefinery	Location	Biomass Used	Biorefinery Methodology	Products
Metan	Reykjavik	Household waste biodegradable waste	Microbial	Methane
Prokatin	Reykjavik/ Ölkelduháls	Geothermal power plant gasses, H_2S , CO_1	Microbial	Single cell proteins for feed and sulphur

Table 18: Institutes and Organisations of relevance for the Bioeconomy

Biorefinery	Location	Biomass Used	Biorefinery Methodology	Products
Center for Systems Biology, University of Iceland	Reykjavik	Microalgae	Microalgal cultivation in photobioreactors. Synthetic biology	
University of Akureyri	Akureyri	Marine, microalgae, bacteria, waste streams	Bioprocessing, Microbial bioconversions	

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2.4 Bioeconomy in the Faroe Islands

Sigrún Elsa Smáradóttir, Matis, Iceland and Janus Vang, iNOVA, Faroe Islands

The text in this chapter is to some extent based on the report "Future opportunities for bioeconomy in the West Nordic Countries", published by the Nordic Council of Ministers in February 2015 (http://norden.diva-portal.org/smash/record.jsf?pid=diva2%3A791350&dswid=7619).

2.4.1 Infrastructure relevant for biorefinery technologies in the Faroe Island

The Faroese economy is heavily reliant on primary production, and the biotech sector on the Faroe Islands has mostly been limited to quality control of the production industry.

The recent opening of the Research Park iNOVA, which is equipped with modern equipment such as RT-PCR, Next Generation gene sequencers and mass spectrometry, provides affordable, rent-based access to biotech infrastructure for start-up companies or foreign companies wanting to establish themselves on the Faroe Islands. The first companies to take advantage of the new opportunities are P/F Fiskaaling, which used iNOVA equipment to develop a genetic sex determination test for smolt (juvenile salmon) and Amplexa Genetics A/S, a Faroese owned contract laboratory located in Odense, Denmark, which will perform genetic tests for the National Hospital of the Faroe Islands.

Table 19: Infrastructure relevant for biorefinery technologies in the Faroe Islands

Platform type	Biorefinery	Location	Biomass used	R&D/Refinery methodology	Product(s)
Support					
	Amplexa Genetics	Tórshavn	DNA/RNA	Next gen sequencing and RT-PCR	Researching better fish stock control
	Fiskaaling	Hvalvík	Salmon	Various	Research and development in aquaculture / production of
	Heilsufrøðiliga Starvsstovan	Tórshavn	Various	Various	Quality control of Food and Veterinary products
	iNOVA	Tórshavn	Various	Various	Product development from various bioresources. Tools for biorefineries: Genetics and enzymes / biorefinery organisms.
	University of the Faroe Islands	Tórshavn	Various	Various	Research groups focused on the blue bioeconomy, e.g. focusing on peptides in fish slime

Platform type	Biorefinery	Location	Biomass used	R&D/Refinery methodology	Product(s)
Blue biotechnology: Rest raw materials from fish industry					
	Faroe Marine Products	Leirvík	Fish heads and backs	Fermentation	Fermented fish products for human consumption
	Havsbrún	Fuglafjørður	Fish rest materials	Physicochemical refining	Fish feed for aquaculture and fish oil
Macroalgae					
	Ocean Rainforest	Kaldbak	Macroalgae		Macroalgae for human consumption and biochemical industry

2.4.2 *Blue Bioeconomy*

Fisheries and aquaculture are the two most important contributors to the Faroese economy, accounting for over 91% of the total exports in 2012 (Statistics Faroe Islands, 2014).

Marine bioresources are therefore the most important biological resources in the Faroe Islands. In order to have a positive impact on value creation in the West Nordic countries, there is a need for investment in research, innovation and technology along with strengthening the fish stocks.

As Denmark leads the Nordic council of ministers in 2015, a three-year chairmanship program (2015–2017) has been put forward. One important component of the program is the blue bioeconomy program led by the Faroe Islands, focusing on the West Nordic region. The project will focus on four main themes: pelagic fish, white fish, algae and aquaculture (http://www.norden2015.fo/english-edition/the-faroese-charimanship-programme/)

2.4.3 *Biorefinery development*

Biorefinery opportunities lie in rest materials feedstock from the fish industry and in seaweed cultivation offshore and subsequent processing. Existing industries are Faroe Marine Products, which produce fermented fish heads and backs for human consumption (exported to Nigerian markets), and Havsbrún, which uses rest raw products from the fishing industry to produce fish feed for aquaculture and fish oil.

Research infrastructure is being established at the well-equipped and spacious research facilities of iNova (http://www.inova.fo/) in Tórshavn. Expertise is building up and collaboration with various Nordic and other international groups has started. There are possibilities for collaboration within the West Nordic region where similar interests and bioresources are found, especially in blue biotechnology, in bioprospecting of marine organisms, microbes, algae and invertebrates, in seaweed utilization and for complete fish harvests. Ambitious and highly advanced development is in progress on Faroe Islands in offshore cultivation and the subsequent utilization of seaweed by Ocean Rainforest (http://oceanrainforest.com/).

2.4.4 References

http://norden.diva-portal.org/smash/record.jsf?pid=diva2%3A791350&dswid=7619
http://www.inova.fo/
http://oceanrainforest.com/

2.5 Bioeconomy in Greenland

Sigrún Elsa Smáradóttir, Matis, Iceland and Amialie Jessen, Asbjørn Brandt, Birgitte Jacobsen. Ministry of Fisheries, Hunting and Agriculture, Greenland.

The text in this chapter is partly based on the report "Future opportunities for bioeconomy in the West Nordic Countries", published by the Nordic Council of Ministers in February 2015 (Smáradóttir *et al*. 2015), (http://norden.diva-portal.org/smash/record.jsf?pid=diva2%3A791350&dswid=7619). A special thanks goes to The Ministry of Fisheries, Hunting and Agriculture in Greenland for their significant contribution and assistance in compiling the information.

Businesses that use biotechnology to transform biomass have not yet developed in Greenland. Even so, the prospect for future development and identification of opportunities in this field in Greenland can be good as Greenland is rich in bioresources. Today the bioeconomy plays a big role in Greenlandic economy. Fishing is by far the most important export sector in Greenland's economy. Fishery export comprises 91% of merchandise exports (Ögmundsson 2014).

2.5.1 Potential and infrastructure

The possibilities for fish farming are being considered along with cultivating macro algae. Trout and mussels have been cultivated earlier with little success.

Private companies have applied for permission to collect seaweed for test collections in order to start commercial production in the near future. Arctic seaweed production is a unique opportunity that can be developed in Greenland as a supplement to commercial fisheries and hunting and also for local cuisine in restaurants.

The fishingiIndustry has ongoing research into producing fish oil and fish meal and intends to continue to develop this process.

Seals are the most frequently hunted wild animal in Greenland in 2010, with 156,000 individuals hunted (Grønlands statistik 2013). Seal meat is used both for human consumption and as feed for sledge-dogs, and the skins are sold for processing (Ministry of Fisheries Hunting and

Agriculture rev. 2012). With the right publicity and marketing effort, sealing in Greenland could make a good livelihood for the Inuit hunters and draw the attention of the fashion industry to skins as a valuable material and a sustainable living for the Inuit in harmony with nature. Meat and other products from the seals can possibly also contribute to food security in underdeveloped countries as a protein supplement.

Dried meat from caribou and musk ox is a business under development through the initiatives of small private companyies and has great potential.

There are several scientific projects on enzymes research as well as agriculture microorganisms in Greenland, led by the University of Copenhagen.

In Greenland the Arctic Technology Centre (ARTEK) educates engineers and carries out research and innovation projects in Arctic technology. The centre and its activities are anchored both in Greenland and in Denmark. The centre is a collaboration between Teknikimik Ilinniarfik, KTI (Tech College Greenland) in Sisimiut and the Technical University of Denmark (DTU) in Lyngby and is organisationally a part of the department of Civil Engineering (DTU BYG). The activities take place in close collaboration with the Greenlandic society, local Greenlandic authorities and industries. The Constructions and Physical Environment Department at ARTEK is an interdisciplinary group, focusing on research and education in cold climate science and engineering related to constructions and transportation infrastructure in the cryosphere (snow, ice, permafrost) and arctic marine environment. The department seeks innovative approaches to solve research problems and adapt conventional technologies to cope with the cold climate. These efforts will contribute to stronger infrastructure and the increased innovation capacity necessary when furthering the economy through use of the natural resources, including bio resources.

Food processing is also being developed by small private companies, some with rather good success with sale through shops in the larger towns. This area also has great potential for development.

Inuili is a modern technical school that trains staff in all food-related industries and employment. Iniuli is also a resource centre that collects and analyses data and disseminates knowledge for the promotion of food and food-related issues, paying special attention to more and better use of ingredients from Greenland.

Greenlandic agriculture and the Agricultural Consulting Services aim to support Greenland's agricultural development. The Upernaviarsuk experimental farm is the Greenlandic Government's research and training centre for the agricultural sector. Within the area of plant cultivation, research is conducted on various perennial types of grasses for the production of hay and silage, including experiments with annual feed crops such as grains, primarily rye, barley and oats, as well as ryegrass and varieties of the cabbage family. There is a small agricultural school at Upernaviarsuk.

VFMG is the veterinary and food authority in Greenland and is the general authority on food issues. One of its additional obligations is to act both as consultant and facilitaor (e.g. in technical matters and optimization of quality) in the development of the food industry in Greenland, as reflected in training programs in all steps of the food chain. Currently under development are education programs for primary producers, and the development of self-monitoring/inspection programs with novel activities at existing and up-start food companies.

For more information please contact the Ministry of Fishery, Hunting and Agriculture at APNN@nanoq.gl

There are many challenges that will not be mentioned here when looking towards the future at possible biotech businesses in Greenland. However, the issue of transport needs to be addressed. Overland transport in Greenland is almost solely within each community/settlement, because the infrastructure (roads and trails) is extremely limited. This is primarily due to the Arctic weather conditions and the vast distances between towns. This is a major challenge in terms of utilization of raw rest materials from the fishing industry.

The Government of Greenland supports sustainable use of all living resources, including marine mammals, based on sound biological advice; however both international obligations and restrictions restrict or forbid commercial use and trade. There is a potential in products such as proteins and oils from certain seal species. Other marine mammals are subject to CITES rules and there is no export or commercial use of them.

Greenland has no research institute focusing on increasing value and the development of the economy from bioresources. The establishment of such a research and development institute/company for exploring biotechnological possibilities and for innovation in the bioeconomy could be highly beneficial for Greenland; a focus on research and innovation in this field could result in added value from a more developed value chain from bioresources in Greenland.

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2.6 Bioeconomy in Sweden

Eva Nordberg Karlsson, Biotechnology, Dept Chemistry, Lund University, Sweden and Josefin Ahlqvist, LU Open Innovation Center, Lund University, Sweden.

2.6.1 Policy and drivers for the Bioeconomy in Sweden

In Sweden the bioeconomy is defined as an economy based on:

- A sustainable production of biomass to enable increased use within a number of different sectors of society. The objective is to reduce climate effects and the use of fossil-based raw materials.
- An increased added value for biomass materials, concomitant with a reduction in energy consumption and recovery of nutrients and energy as additional end products. The objective is to optimize the value and contribution of ecosystem services to the economy (JCR, SCAR, 2014).

This is in accordance with the EU-definition: "The bioeconomy encompasses the production of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy. It includes agriculture, forestry, fisheries, food and pulp and paper production, as well as parts of chemical, biotechnological and energy industries. Its sectors have a strong innovation potential due to their use of a wide range of sciences (life sciences, agronomy, ecology, food science and social sciences), enabling and industrial technologies (biotechnology, nanotechnology, information and communication technologies (ICT), and engineering), and local and tacit knowledge" (Commission Staff Working Document of COM, 2012).

The highest ranked drivers include:

- Contribution/implementation of the EU strategy on Bioeconomy.
- Independence from fossil resources/security of supply.

- Development of new bioeconomy sectors (bioenergy, industrial biobased products).
- New business, increased employment.
- Mitigation of climate change/adaptation to climate change.
- Resource efficient economy (reduction of waste, use of residues) (JCR, SCAR, 2014).

Sweden has a national research and innovation strategy for a biobased economy (Formas, 2012). A national bio-economy strategy is on its way (JCR, SCAR, 2014).

2.6.2 Swedish bioresources of major importance for current and future bio-refineries

The main biomass resources in Sweden today come from *forests* and *agricultural lands*, while *marine resources* (including fisheries, microalgae and macroalgae) are relatively poorly utilized. For example, free floating macroalgae today pose an economic burden on coastal communities. In Skane alone, more than 20,000 tonnes wet weight macroalgae/year is transported away from harbours and beaches (Bucefalos, 2012), and biorefining of this waste would be a significant added value. Ongoing work in this field includes biogas production from macroalgal waste and is being evaluated in the municipality of Trelleborg (contact: M Gradin), where there are some challenges regarding heavy metal content (Onnby, 2015). Recent reports have also shown that there is a large productivity potential in for example macroalgae (calculated at 10–70 tonnes dryweight/ha, year, dependent on species).

Forest land covers the largest surface of Sweden, but has lower productivity (approximately 0.4 tonnes dryweight/ha, year), compared to both agricultural crops (e.g. cereals, 10–30 tonnes dryweight/ha, year) and marine macroalgae, 10–70 tonnes dryweight/ha, year).

Major forest biomass includes spruce, pine and birch. Sweden has a land area of 40.7 million ha, with 28.3 million ha forest land, of which 23.2 million ha is productive forest land. This holds approximately 3,350 million m^3 forest wood. Today, about 80–90 million m^3 is harvested per year (Swedish forest industries statistics) and utilized mainly for timber and pulping. In a biorefinery, the (remaining) lignocellulosic raw material from the forest biomass can be fractionated into a number of useful fractions, such as cellulose, hemicellulose and lignin, which then with the right process technology can be individually converted into value-added products such as chemicals, materials, biofuels, electricity and heat. In addition, a survey of byproducts from the forest industry (Ekman *et al*., 2013) for example points to significant amounts of added materials for biorefining of extractives, which are not utilized today (Table 20).

Table 20: Survey of total amounts of byproducts from the forest industry in Sweden and potentially extractable high value compounds

Waste resource	Amount Mm³/year	Current use	Potential extractable compounds
Bark (hardwood, birch)	1–2	Energy (forest industry)	Antimicrobials
Bark (softwood)	6–8	Energy (forest industry)	Antioxidants
Sawdust	3–5	Pellets (energy)	Bio-oils, lignocellulose
Knots	N.A	Energy	Glycerides, steryl esters, fatty acids, sterols, fatty alcohols
Needles, tops, twigs	2–4	Energy (heat, power)	Essential oils, resins
Tall oil	N.A	Adhesives, detergents, aromas, biodiesel etc.	Squalene, plant sterols
Black liquor	N.A	Energy (gasification)	Hemicellulose, lignin components

Note: Adapted after Ekman *et al.*, 2013 – N.A = not applicable.

Agricultural crops are mainly grown in the southern part of the country. According to FAO (2010) Sweden is among the world's top (40) producers of *wheat* and *sugar* (from sugarbeet). Other significant agricultural products include potatoes (for starch production) and rape seed for vegetable oils.

Wheat production involves 397,000 ha, resulting in 2,143,000 tonnes. (This results in 1,019,000 tonnes in *cereal exports*).

Sugar beet production involves 38,000 ha, resulting in 1,974,000 tonnes (here export and import are 180,000 vs 192,000 tonnes).

In the survey by Ekman and coworkers (2013), several potential byproducts for biorefining of extractives from agricultural resources were listed (Table 21).

Table 21: Survey of total amounts of byproducts from the agricultural industry in Sweden combined with extractable potentially high value compounds from these byproducts

Waste resource	Amount (tonnes/year)	Current use	Potential extractable compound
Straw (wheat)	260,000–1,200,000	Animal farming, energy	Wax products, hemicellulose, Polycosanols
Cereal husks and other waste (mills)	57,000	Energy	Hemicellulose, Tocoferols, sterols
Potato juice (starch prod.)	100,000–200,000	Fertilizer	Proteins, amino acids, glycoalkaloids
Potato pulp (starch prod.)	20,000–40,000	Animal feed (fiber prod)	Pectin and hemicellulose, rhamnogalacturonan
Potato waste (food prod)	40,000–50,000	Biogas/incineration	Glycoalkaloids, phenolic acids etc.
Selected fruit and vegetable wastes			
Carrot	5,000–10,000	Animal feed/Biogas	α and β carotene
Onion	1,000–5,000	Animal feed/Biogas	Quercetin (antioxidant)
Orange (juice prod)	5,000–10,000	Animal feed/Biogas	Naringenin, Hesperitin, vit C (antioxidants)
Apple	500–1,500	Animal feed/Soil improver	Quercetin, cyanidin etc. (antioxidants)
Lettuce	1,000–5,000		Quercetin derivatives (antioxidants)
Brewery waste			
Draff/Brewer's spent grain	60,000	Animal feed	Proteins (hemicellulose)
Yeast	10,000	Animal feed	Proteins

Note: Adapted after Ekman *et al*., 2013.

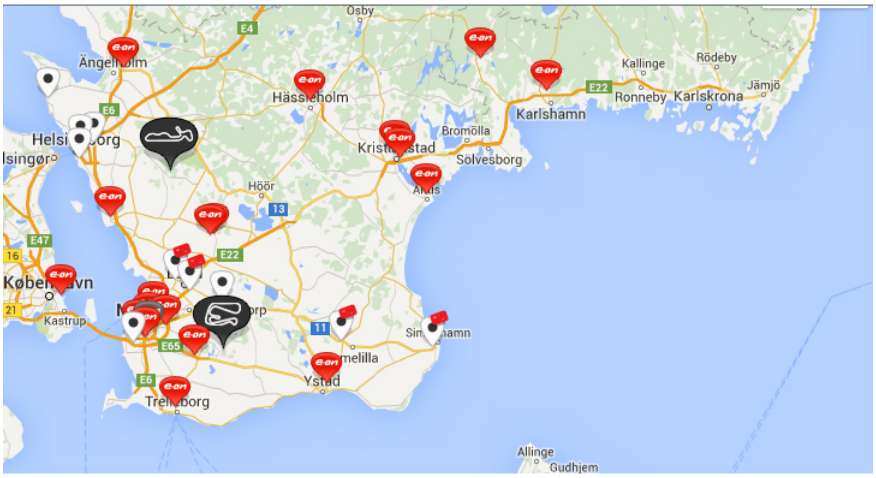
2.6.3 Product range from biorefineries

It is important to consider that methodologies for the transition to use biomass instead of fossil raw materials *should adapt to the structures of biomass*, instead of the less complex structures of fossil resources. *Hence, it may not be relevant to be too specific in suggestions of product*, but rather focus on functions, because novel refining technologies and value chains need to be developed. It will be important to include pretreatment techniques before the processing steps, and the process design has to be adapted. New and innovative technology platforms are needed for separation, fractionation, extraction and conversion of the biomass to maximize the value of the feedstock.

Manufacturing from biomass will however, definitely result in a large number of products for a large number of distinct business segments. Some foreseen areas include fuels, chemicals and food and feed additives, and biotechnological tools. Examples of suggested products from these areas are given below.

Fuels: The main emphasis on biofuels has thus far been on bioethanol, biogas, and biodiesel (RME or AFME). Political instruments have been used to introduce these products to the market. Hence Sweden is in the forefront of implementing biofuels for transportation, and a considerable amount of infrastructure has been developed to commercialize transportation fuels. This has resulted in more than 1,000 filling stations for ethanol (E85) distributed over the entire country, and more than 150 filling stations for biogas (predominantly located in the south of Sweden, where most production plants are also located (Martin & Coenen, 2015) (see for example Figure 4). Filling stations supplying biodiesel (mainly RME) for primarily heavy traffic are also available (again primarily in South Sweden), but are not as common because engines on standard diesel vehicles are adapted for a certain percentage of biodiesel (normally up to 10%).

Figure 4: Map showing filling stations for biogas in the the south Swedish region Skane. Skane accounts for 20% of the Swedish biogas production (0.3 Twh in 2011)



Source: Martin & Coenen, 2015.

Increased research interest is currently directed towards aviation fuels which today lack biobased alternatives, and research in this field has been initiated.

In the future it is expected that there will be more and more coproduction of fuels and other higher value products, e.g. chemicals (platform and special) as well as food and feed additives, as exemplified below.

Chemicals: A number of reports have been released on potentially interesting chemicals produced from biobased rawmaterials. A main focus is on the sugar platform, but potential lignin-based products are also starting to attract attention. (PNNL report on sugar platform 2004, and lignin 2007).

Groups of interest include:

- Platform chemicals such as diacids, dihydroxypropionic acid, aspartic acid etc, as reviewed by Turner *et al*., 2007 (Table 22). These have a rather low market price but are needed in large quantities. This group for example includes building blocks for polymers, such as bioplastics, which is another product group of interest.
- Speciality chemicals (e.g. lubricants, surfactants), which may vary much in price and functionality.
- Pharmaceuticals (Pharmaceuticals is a traditionally strong sector in Sweden, including many start up companies which are developing novel types of compounds).
- Fertilizers, Minerals for soil. These types of compounds often remain, even after an increased utilization of the rawmaterial stream.

Table 22: Prioritized sugar-derived building blocks as listed by the US Department of Energy, as summarized in Turner *et al*., 2007

Building blocks	No of carbons	Pathways	Derivatives	Direct uses or uses of derivatives
1,4 diacids (succinic, fumaric, and malic)	4	Aerobic fermentation to overproduce C4 diacids from Krebs cycle patways	THF, 1,4-Butanediol, γ-butyrolactone, pyrrolidones, esters, diamines, 4,4-Bionelle, hydroxybutyric acid, unsaturated succinate derivatives, hydroxy succinate derivatives, hydroxybutyrolactone	Green solvents, Fibers (lycra, others), TBD, water soluble polymers
2,5 furan dicarboxylic acid	6	Oxidative dehydration of C6 sugars (chemical) Enzymatic conversion – not known	Numerous furan derivatives, succinate, esters, levulinic acid, furanoic polyamines, polyethylene terephthalate analogs	Furanoic polyesters (bottles, films containers) Polyamides (new nylons)

Building blocks	No of carbons	Pathways	Derivatives	Direct uses or uses of derivatives
3 hydroxy-propionic acid	3	Aerobic fermentation	Acrylates, Acrylamides, esters, 1,3-propanediol, malonic acid, propionol,	Sorona fiber, contact lenses, diapers (super absorbent polymers)
Aspartic acid	4	Conversion of oxaloacetate in the Krebs cycle via aerobic fermentation or enzymatic conversion	Amine butanediol, amine tetrahydrofuran, amine-butyrolactone, aspartic anhydride, polyaspartic, various substituted amino-diacids	Amino analogs of C4 1,4 dicarboxylic acids. Pharma and sweetener intermediates
Glucaric acid	6	One step nitric acid oxidation of starch (chemical) Aerobic fermentation	Dilactones, monolactones, polyglucaric esters and amides	Solvents, nylons of different properties
Glutamic acid	5	Aerobic fermentation	Diols, amino diols, diacids, glutaric acid, substituted pyrrolidones	Monomers for polyesters and polyamides
Itaconic acid	5	Aerobic fungal fermentation	Methyl butanediol, butyrolactone, tetrahydrofuran family, pyrrolidones, polyitaconic	Solvents, polymers (BDO, GBL, THF), nitrile latex
Levulinic acid	5	Acid catalyzed dehydration and decomposition of cellulosics and sugars Biotransformation – not known	δ-aminolevulinate, Methyl tetrahydrofuran, δ-butyrolactone, acetyl acrylates, acetic-acrylic succinic acids, diphenolic acid, levulinate sters	Fuel oxygenates, solvents, polycarbonate synthesis
3-hydroxy-butyrolactone	4	Oxidative degradation of starch Biotransformation?	Hydroxybutyrates, epoxy-δ-butyrolactone, butenoic acid, furans, analogs for pyrrolidones	High value pharma compounds, solvents, amino analogs to lycra fibers
Glycerol	5	Enzymatic or chemical transesterification of oils	Fermentation products, Propylene glycol, malonic, 1,3-propanediol, diacids, propylalcohol, dialdehyde, epoxides, glyceric acids, branched polysters and polyols	Personal/oral care products, pharmaceuticals, foods/beverages, polyether polyols, polyester fibers, antifreeze, humectant, sorona fiber
Sorbitol	6	Hydrogenation of glucose (chemical) Aerobic fermentation or biotransformation	Ethylene glycol, propylene glycol, glycerol, lactic acid, isosorbide, branched polysaccharides	Polyethylene isosorbide, terephthalates (bottles), antifreeze, polylactic acid, water soluble polymers
Xylitol/ arabinitol	5	Aerobic or anaerobic fermentations or enzymatic conversions of lignocellulose	Ethylene glycol, propylene glycol, glycerol, lactic acid, hydroxy furans, xylaric acid, polyols	Non-nutritive sweeteners, anhydrosugars, unsaturated polyester resins, antifreeze

Food/feed and additives: Sweden already has an established food production sector, and the companies in this sector generally possess infrastructures highly relevant for biorefining processes. Hence, increased utilization of agricultural (but also forest) resources, in addition to novel chemicals and fuels, could also include applications in:

- Animal feed.
- Food ingredients and nutraceuticals (e.g. antioxidants, prebiotics).

These two main groups of compounds include use of remaining complex rest products as animal feed, but also separation and production of more specialized higher value components for use as food ingredients and nutraceuticals. For example, extractives from natural resources can be utilized, such as bioactives and antioxidants of the types listed in Table 20.

Biotechnological tools: In addition to the above products, biotechnological tools (biological components e.g.microorganisms and/or enzymes) can be produced using the sugar platform as carbon source. Hence, there is interest in producing monomeric and dimeric sugars from the resources that allow growth of microorganisms, which in turn are used as production aids for specific products (metabolites) or catalysts (enzymes) in novel processing routes.

2.6.4 Examples of publicly funded open access equipment

The biorefining research field has attracted increasing interest during the last 10-year period. *Access to test facilities* for pilot trials in different scales is important for closing the gap between lab-scale production of novel model reactions and products. Test facilities are often supplied by academic research organizations and research Institutes, which are highly relevant actors for the implementation of the bioeconomy. Of special interest during the development stages is the possibility for many users to access equipment that allows development of novel technologies. A few actors have such open access facilities and examples are shown in Table 23. In addition to listed facilities, several other universities and institutes have facilities and infrastructure of great relevance for development of technologies in the field, although not with advertised or established access for external users.

Table 23: Examples of organizations with open access facilities for biorefinery or related applications

Organisation	Location	Biomass used	Description/methodology	Products
SP	www.sp.se *Borås* *Lund* *Göteborg* (Anneli Petersson, Sune Wännström) *Örnsköldsvik* Pilot plant location *Södertälje*: facility for biomass valorization and product development	Any	SP Technical Research Institute of Sweden is an international research institute working in all parts of the innovation chain. Has since 2013 the operational responsibility for a *biorefinery demonstration plant* in m^3-scale(see also home page of SEKAB) in Örnsköldsvik	Any metabolites or hydrolysates
SP Processum AB	www.processum.se *Örnsköldsvik* (Björn Alriksson)	Any	Research institute unit with research related to biorefinery applications Equipment for fermentation in lab and 50 L scale. Extraction and Steam explosion equipment	Any metabolites or hydrolysates
KTH / Bioproduce	www.bioproduce.se *Stockholm* (Andres Veide)	Formats for fermentors	SME located at Albanova (KTH) focusing on contract production of enzymes and microorganisms by fermentation. Facilities for up to 700L scale	Microorganisms or metabolites
LTH (Lund University)/ Chem. eng. (PDU)	http://www.chemeng.lth.se/pdu/ *Lund* (Mats Galbe)	Any	The Process Development Unit (PDU) has a long and succesful tradition within the lignocellulose-to-bioethanol, but also in biorefinery applications. Open access pretreatment, hydrolysis, and fermentation of biomass to ethanol. (Scale is typically 2–20 kg dry matter, fermentation <100L)	Any hydrolysates, microorganism (suitable for STR-fermentation) or metabolite
Max IV	https://www.maxlab.lu.se/sv/maxiv *Lund* (Marjolein Thunissen)	Purified components	Crystallization and synchrotron facility	Structure determination of novel proteins, materials etc
SciLifeLab	http://www.scilifelab.se KTH, SU, UU and KI *Stockholm*	Any	Laboratories equipped for life science related analyses	Proteomics, bioinformatics, genomics, diagnostics etc

2.6.5 Targeted company sectors, with relevant structures for the Bioeconomy

The established industrial sectors targeted as candidates interested in biorefining technologies and biorefineries include the chemical industry, agricultural industry and forestry industry (Table 2.16–2.19). The chemical Industry has an interest to change from fossil raw materials to biomass. The forestry industry and agricultural Industry are both established users of biomass as raw materials, but with interest to complement their product portfolio and increase utilization of the raw material side streams. A fourth important group includes new small companies, often started as spin-offs based on results from research and development projects (see examples from Region Skåne in Table 27), that develop and sell technologies, or set up new production processes, leading to new employment opportunities.

The forest industry plays a major role in the Swedish economy, and is predicted to be an important player in the bioeconomy Table 24). The forest industry is spread over the entire country, and *directly employs close to 60,000 people (close to 200,000 jobs including subcontractors*), although the numbers have been decreasing in recent years. Exports were valued at SEK 123 billion in 2012, accounting for between 10 and 12% of Swedish industry's total employment, exports, sales and added value (FAO, 2012; Swedish forest industry, 2013), and for between 9 and 12% of Swedish industry's total employment, exports, sales and refinement value (Swedish Forest Industries Federation, 2014). The industry is heavily export oriented and Sweden is one of the top five forest product exporters in the world (FAO, 2011). Sweden's expanding forests account for over 85% of its bioenergy output, of which only a fraction (around 5%) is used to produce transportation biofuel (Fethers, 2014).

From the forest product sector (http://www.skogsindustrierna.org/om-skogsindustrierna/medlemmar/medlemskarta) production plants are available in sectors including pulp and paper (approximately 50, Table 24), sawmills and wood processing mills (together approximately 145) as well as other types of plants (approximately 70, of which a few are related to biorefining, mostly wood pellets production, together with some other bioconversion companies listed in Table 24). Even though this part of biomass conversion is traditional, upgrading of side streams and byproducts to novel processes is a current common interest, driven by the interest of organization representing Swedish forestry product processing companies (see also Table 19 below). Most Swedish mills also utilize byproducts for energy production (and if internal, this is not included among the products in Table 24).

The Swedish Food industry (Table 25) has a strong presence in southern Sweden where the main part of the agricultural sector is also located. Agricultural products are refined in the *food processing industry which has 52,000 employees, in approximately 3,100 companies*, and exported products worth about SEK 54 billion in 2010. Relevant infrastructures are located in industries related to forest product manufacturing and agricultural product manufacturing.

Food manufacturing also have significant facilities. Several of the food manufacturing companies in Sweden are also importers of raw materials that are processed in the plants. These include manufacturers with high relevance for processing biomass, such as oils and fats (e.g. Aarhus Karlshamn) and cereals (Lantmännen) (Table 25). Several multinational companies in the food sector have production facilities in Sweden, including for example Unilever and Kraft foods.

In addition to forestry and food manufacturing industries, the chemical industry is another large sector with relevant infrastructure, and comprise apoximately 450 companies (in 2010 employing approximately 34,000 full time staff). These industries form three significant clusters in the more densely populated regions surrounding Stockholm/Uppsala, Gothenburg and Malmö/Lund. Many of these industries have equipment suitable for synthesis, which could be used for organic chemistry reactions as well as enzymatic conversions (while microbial conversions may require new investments), and some actors during the recent years have moved towards biobased products. This industry is primarily represented by a few large companies, while the majority are smaller. In 2010, an inventory (Mossberg, 2013, showed that 31 companies had more than 250 employees (Table 26), 75 companies were in the range 75–249 employees, and the majority (332 companies) were smaller, with less than 50 employees. The pharmaceuticals sector has dominated the total employment figures, but has decreased significantly during the last years.

Table 24: Forestry bioprocessing/biorefining activities

Corporation (organization)	Location forestry – pulp and paper mills	Current Product, capacity (tonnes)	New products (if defined)
ABB	ABB Figeholms bruk,	Cardboard <100,000	-
Aditya Birla	Domsjö Fabriker, Örnsköldsvik	Pulp 300,000, lignosulfonate, ethanol etc.	Textile fibers, any novel product of interest from waste/ side streams (e.g. black liquor)
ATA Group	Waggeryd Cell AB, Vaggeryd	150,000 tonnes mech pulp	-
BillerudKorsnäs AB	BillerudKorsnäs Rockhammar AB, Frövi	Pulp	Defined interest in bioplastics
	Billerud Korsnäs Skärblacka AB, Skärblacka	Pulps 400,000, and paper types 400,000	-
	BillerudKorsnäs, Gävle	Pulp 800,000, paper 800,000	-

Corporation (organization)	Location forestry – pulp and paper mills	Current Product, capacity (tonnes)	New products (if defined)
	BillerudKorsnäs Karlsborg AB, Karlsborgsverken	Pulp 400,000, paper (kraft, sack) 200,000	
Duni AB	Rex Cell, Bengtsfors	Soft paper, <100,000	
Fiskeby Int Holding AB	Fiskeby board AB, Norrköping	Chipboard, cardboard , 200,000	
Grycksbo paper holding AB	Arctic Paper Grycksbo AB	Paper 300,000	
Klippans bruk	Klippans bruk, Klippan	Tissue paper, <100,000	-
Lessebo paper	Lessebo paper AB, Lessebo	Hand made paper, <100,000	-
LE Lundbergföretagen AB	Holmen Iggesunds bruk, Iggesund	Pulp 400,000, paper 400,000	
	Holmen Paper AB, Hallsta pappersbruk, Hallstahammar	Newspaper SCpaper 700,000, pulp 800,000	
Metsä group	Metsä Tissue AB, Mariestad	Soft paper, <100,000	See data from Finland for interest from Metsä group
	Metsä Tissue AB, Nyboholms bruk, Kvillsfors	Tissue paper <100,000	
	Metsä Board, Husum, Sweden	Pulp 800,000, paper 800,000	
Mondigroup	MondiDynäs AB, Väja	Pulp 300,000, paper (sack, kraft) 300,000	
Munksjö Group	Munksjö paper AB, Jönköping	Decor, Speciality papers <100,000	
	Munksjö Aspa bruk AB, Aspabruk	Pulp, 200,000	
	Munksjö paper AB, Billingsfors bruk, Billingsfors	Pulp <100,000, paper <100,000	
Nemus Holding AB	Arctic paper Munkedals AB	Fine paper, 200,000	-
Nordic paper AB	Nordic paper Bäckhammar AB, Kristinehamn	Pulp 200,000, paper 200,000	
	Nordic paper Åmotsfors AB, Åmotsfors	Paper <100,000	
	Nordic Paper, Seffle AB	Pulp <100,000, speciality paper <100,000	
Panier Svenska AB	Svanskog bruk AB, Svanskog	Cardboard <100,000	
Rottneros AB	Rottneros bruk AB, Rottneros	Pulp 200,000	
	Vallviks bruk AB, Vallvik	Pulp 300,000	

Corporation (organization)	Location forestry – pulp and paper mills	Current Product, capacity (tonnes)	New products (if defined)
Stora Enso AB	Stora Enso Nymölla AB, Bromölla	Paper, 500,000 Pulp, 400,000 tonnes	Participates in bioprocess mapping actions
	Stora Enso Packaging Skoghalls bruk, Skoghall	Pulp 700,000, cardboard 800,000	
	Stora Enso publication paper, Hyltebruk	Pulp 400,000, paper >800,000	
	Stora Enso Fors AB, Fors	Pulp 200,000. Cardboard 500,000	
	Stora Enso Kvarnsveden Mills, Borlänge	Pulp >800,000, paper >800,000	
SCA	SCA Ortvikens pappersbruk, Sundsvall	Pulp >800,000, newspaper >800,000	Defined interest in side products from pulping streams as well as products from underutilized fractions pre-pulping. Also having a research fund connected to its interest areas for support of novel actions
	SCA Hygiene Holding, Lilla Edet	Hygiene paper 200,000	
	SCA Packaging Obbola AB, Obbola	Pulp 300,000, liner 500,000	
	SCA Packaging Munksund AB, Piteå	Pulp 300,000, liner 400,000	
	SCA Östrands massafabrik, Timrå	Pulp 600,000	
Smurfit Kappa Packaging Sweden	Smurfit Kappa Kraftliner	Pulp 600,000, Liner 800,000	collaboration with Chemrec
Södra	Södra Cell Mönsterås	Pulp 800,000	Defined interest in up-grading side streams from pulping processes
	Södra Cell, Värö	Pulp 500,000	
Sofidel group	Swedish Tissue AB, Kisa	Hygien prod, Tissue paper <100,000	
Swedpaper AB	Swedpaper AB, Gävle	Sackpaper	
Corporation	**Other types of industries**		**New Product**
AB Krekula & Lauris Såg	Pajala Bioenergi AB		Bioenergy
Moelven Industrier AB	Vänerbränsle AB		Energy
Åmotsfors energy	Åmotsfors energy AB		Energy from waste
Stenqvist	Dals Långed Coating AB		Packaging from biomass

Corporation (organization)	Location forestry – pulp and paper mills	Current Product, capacity (tonnes)	New products (if defined)
Stora Enso AB	Stora Enso Bioenergi AB		Bioenergy
VIDA AB	Vida Energi AB		Pellets for heating
Clean Tech East holding AB	Ystad pellets AB		Pellets for heating
SCA	SCA Norrbränslen		Pellets
Södra	Södra Energi		Pellets
Derome	Derome Bioenergy		Pellets
Neste Oil	Neste Oil		Solutions for renewable fuels
Chemrec	Chemrec		Gasification of black liquor

Note: Pulp and paper corporations and mills, as well as other types of forest products companies, located in Sweden (from 2010, or later if available). The biomass used is in all cases lignocellulosic, and streams from pulping or sawmill processing. Organisations with defined novel product interests and also others are included, as collaboration on new products is often relating to research projects in collaboration with research institutes and academia, and hence not defined in advance.

Table 25: Examples of (larger) food manufacturers in Sweden including actors with specific biorefining activities

Manufacturer	Location	Current products	Novel product spectrum
Arla Foods	(head quarters in Denmark)	Dairy products and juices (3,200 employees)	Milk related products and additives
Aarhus Karlshamn, AAK AB	Karlshamn and Malmö , Sweden	Oils and fats (2,207employees)	Chemicals related to oily substrates
Lantmännen,	Stockholm and Malmö, Sweden	Cereal, feed and poultry products (2,000 employees)	Upgrading of cereal based byproducts and products
	Lantmännen Agrovärme, Jönköping		Energy from biomass
	Lantmännen Agroenergi AB		Pellets for heating
Milko		Dairy products and juices (641 employees)	n.d.
Nordic Sugar	Part of Nordzucker, Germany	Sugar and molasses (467 employees)	Rawmaterial byproduct upgrading
Procordia Food	Part of Orkla, Norway	Convenience foods (993 employees)	Prebiotics and extractives from food processes
Pågen		Bakery and cereal products (1,304 employees)	Prebiotic fibers and related products
Santa Maria	(Paulig)	Spices (498 employees)	n.d.

Manufacturer	location	Current products	Novel product spectrum
Scan	Sweden	Meat and ready to eat products (2,860 employees)	Slaughterhouse waste / by-products
Skånemejerier		Dairy products and juices (746 employees)	n.d.
Spendrups		Beer ,wine, soft drinks (1,117 employees)	n.d.
Absolut	Pernod, (France)	Distilled spirits, Vodka (440 employees)	n.d.
Findus Sweden AB		food and ingredients (785 employees)	Supplying byproducts to research project (SureTEch) funded by Formas.
Lyckeby Starch AB Lyckeby Culinar AB	Kristianstad/ Fjälkinge	starch production from potatoes and starch fiber products feed etc. (ca 275 employees)	Valorization of side-streams
Kiviks musteri and holding AB	Kivik	Production of Fruit juices etc,(132 employees)	with interest to utilize byproducts e.g. press cakes etc.

Note: 1. The number of employees indicated (from 2010, or later if available).
n.d. = product range not determined.

Table 26: The fifteen largest chemical industry companies in Sweden in 2010, according to Mossberg, 2013

Chemical product manufacturer	Location	Product Sector	Novel products
Astra Zeneca	(7,277 employees in 2010, but has down-sized significantly in Swe-den during the last years, e.g. closing plants in Lund and Söder-tälje.) Parent company in GB	Pharmaceuticals	Biobased Pharmaceuticals
Akzo Nobel Group	More than 10 companies in Sweden. Parent company in NL. (806 employees in 2010)	Chemicals: Surface chemistry and Functional chemicals	Biobased chemicals – same field
Apoteket	(production & laboratories) (438 employees in 2010)	Pharmaceuticals	Biobased variants
AGA gas	Parent company in DE. 907 employees in 2010	Basic Chemicals	Biobased platform / basic chemicals
Borealis	Parent company in AE. 906 employees in 2010	Basic chemicals, plastics	Biobased variants – same field
Eka Chemicals (part of the Akzo Nobel group)	Parent company in NL. 908 employees in 2010	Basic Chemicals	Biobased variants
Flugger	Parent company in DK. 474 employees in 2010	Paints, coatings adhesives	Biobased alternatives
FreseniusKabi	Parent company in DE. 926 employees in 2010	Pharmaceuticals	Biobased alternatives

Chemical product manufacturer	Location	Product Sector	Novel products
GE Health Care Biosciences	Parent company in US. 1,632 employees in 2010	Pharmaceuticals	Biobased alternatives
McNeil	Parent company in US. 756 employees in 2010	Pharmaceuticals	Biobased alternatives
Octapharma	557 employees 2010	Pharmaceuticals	Biobased alternatives
Perstorp group	Perstorp, .1,500 employees in Europe	Coatings, resins, Lubricants, plastics, as well as food and feed	Biobased alternatives
Phadia	Parent company in LU. 418 employees in 2010	Pharmaceuticals	Biobased alternatives
Preem	Parent company in CY. 1,315 eployees in 2010	Refinery. Tall oil processing	Biobased alternatives
Swedish Orphan Biovitrum	434 employees in 2010	Pharmaceuticals	Biobased alternatives

Upstart companies and SMEs (Table 27) are actors that continue to boost development in the field, in collaboration with academia, public sector (which has more and more impact through public procurement) and large companies. Networks between small and larger companies are often created via interest organizations (Table 28). Both large and small companies are frequently members, and create networks/clusters which can be influential bodies for contact with stakeholders and funding agencies. A selection of influential interest organizations, which link companies with related interests for the different sectors together, is shown in Table 28.

The number of small and medium enterprises (SMEs, 0–249 employees) in Sweden is very large, and statistics (http://www.ekonomifakta.se/sv/Fakta/Foretagande/Naringslivet/Naringslivets-struktur/) have shown that approximately 1,000,000 SMEs are active in Sweden (of which more than 2/3 are single person "micro" companies without employees). This makes it challenging to survey SMEs with a role in biorefining over the entire country. Since the SMEs, however, often supply interesting complementary products and know-how to existing industries, a survey has been made for the southernmost region of the country (region Skåne), listing companies from the region with activities related to the bioeconomy (Table 26). It is worth noting that incubators (often in close proximity to the university) host many of the start-up companies (frequently those with less than 5 employees). A similar pattern is therefore to be expected in other parts of the country, where corresponding incubators are located close to academic institutions.

Table 27: Examples of SMEs in region Skåne, active during 2013/2014, in fields relevant for development of the bioeconomy

Organisation	Location	Employees 2013/2014	Description
Essentia Protein Solutions	Klippan	91	Protein from slaughterhouse byproducts
Cereal Base CEBA AB	Malmö	74	Innovative food from cerealbased resources
Active Biotech	Lund	61	Medical and biotech products
Oatly AB	Malmö/Landskrona	58	Novel cerealbased food products
Mariannes Farm AB	Strövelstorp	43	Roots and vegetables, with interestin recovering byproducts
Camurus AB	Lund	35	Biotech and medical related products
AB Jordberga Gård	Klagstorp	13	Biogas production facility for byproducts from farming
Svenskt gastekniskt center	Malmö	9	Energy technology
Enzymatica AB	Lund	8	Innovative products by enzyme technology
Anolytech	Ystad	7	Chemical processing equipment
Reac Fuel AB	Lund	7	Equipment and know-how for biomass degradation to fuel
Bioprocess Control	Lund	6	Control equipment for biogas production
Simris Alg AB	Hammenhög	6	Production of and products from microalgae
Norups Gård Bioraff AB	Knislinge	5	Products from vegetable oil & other biotechnological products
Aventure AB	Lund	4	Food technology related product development
Fermentas Sweden AB	Helsingborg	3	Trade and advice on biochemical products distributor of molecular biology products
Enza Biotech AB	Lund	3	Biobased surfactants
Speximo AB	Lund	3	Biobased stabilizing emulsions
C5 ligno technologies in Lund	Lund	3	Microbial degradation of lignocellulose
ScanBiRes AB	Alnarp	3	Biotechnology related projects
In vitro plant tech AB	Limhamn	2	Genetically developed plants
BioDev Ab	Helsingborg	2	Biotech products, particles
Bioactive polymers i Lund AB	Lund	2	Novel polymers and lipids with medical applications

Organisation	Location	Employees 2013/2014	Description
CR Development AB	Lund	2	Innovative product developments in chemistry and formulation science
BG Innovation Sweden AB	Landskrona	2	Agent for environmental technology and renewable energy etc.
Crop Tailor AB	Lund	1	Biotechnological plant breeding for applied purposes
European Institute of Science AB	Lund	1	Products and methods in medical technology and biotechnology including e.g. cosmetics and health care
Immune Biotech Medical Sweden	Malmö	1	Medical related products including probiotics
Protista Biotechnology AB	Bjuv	1	Biotechnology based products
Biosurface Innovations AB	Malmö	1	Research and development of biomaterials etc.
CeLac Sweden AB	Höör	1	Biotech and microbiology for food and feed
Ceffort AB	Lund	1	Establish collaborations in the value chain bio-tech/biomedicin
Lundagrion AB	Lund	1	Agroindustrial processing, development and equipment
Thylabisco AB	Lund	1	Development and production of novel food ingredients
BioFuel-Solution i Malmö	Limhamn	1	Bioenergy related processing
SAAN Energy AB	Lund	1	Material components and technology for novel energy e.g. fuel cells
NBR	Bjärred	1	Nordic beet research foundation –related to sugar beet research/exploitation
Novaferm AB	Oxie	1	Fermentation and bioreactor equipment
Bioextrax AB	Malmö	0	Biopolymer extraction
Carbiotix AB	Lund	0	Prebiotics from agromaterials
Indienz AB	Lund	0	Industrial/environmental biotechnology Accessible biorefinery plant for customer service
Sweden Water research AB	Lund	0	Water processing techniques
SwePharm AB	Lund	0	GMP production plant, for extracts and health related natural products from plants Accessible plant for contract manufacturing
Igelösa Nutrition Science AB	Genarp	0	Novel health related agricultural products
ProEquo AB		0	Animal probiotics
Celltrix AB	Åstorp	0	Biotech production
Cyclicor AB	Lund	0	Sustainable chemical processing for polymer production (plastics)

Organisation	Location	Employees 2013/2014	Description
Pheronet AB	Lund	0	Substances for biological insect control
Hydrogene Lund AB	Lund	0	Development of biochemically produced substances
Siko Bioprojektering AB	Smedstorp	0	Production of process technology equipment
GlucaNova AB	Lund	0	Oatbased food technology development
Phenoliv AB	Lund	0	Innovative biobased products from surplus plant oils
Synbiotics AB	Höganäs	0	Novel types of food related products
NutraGreen Technical & Research solutions	Hjärup	0	Pressurized technologies solutions
Intenz biosciences AB	Lund	0	GreenChem related research
Enzymatica Care AB	Lund	0	Enzymebased products for cosmetics and healthcare
TwoPac Laboratories AB	Eslöv	0	Food and medical products

Note: The list does not include companies in medical technology and related areas. A large number of SMEs solely working with consultancy tasks are also not shown.

Regarding public initiatives, the Region of Skåne is currently working on a road map for the implementation of the bioeconomy in the Region. Several municipalities, for instance in the Cities of Malmö, Lund, Kristianstad and Helsingborg work in several projects for a sustainable city. Their efforts towards a biorefinery concept include mostly activities using and producing biogas from municipal food/household waste and public transportation.

Table 28: Some selected interest organizations representing industrial sectors relevant for implementing the Bioeconomy

Organisation	Web-address	Description
Innovations och Kemiindustrierna (IKEM)	www.ikem.se	IKEM (Innovation and Chemical Industries in Sweden) is an industrial and employer organisation (founded 2012) represent around 1,400 Swedish and foreign-owned companies. Member companies work in a broad cross-section of the chemical industry (e.g. plastics, pharma, biotech) including producers, distributors and users Contact: Nils Hannertz
Livsmedels-företagen	www.livsmedelsforetagen.se	The Swedish Food Federation (Livsmedelsföretagen) approx, 800 member companies, representing all kinds of companies in the food industry, from small, local companies to large, international groups
Skogsindustrierna	http://www.skogsindustrierna.org/	The Swedish Forest Industries Federation represents around 50 pulp and paper manufacturers and around 115 sawmills. It also represents a number of companies that are closely associated with pulp and paper or sawn timber manufacture. Contact: Jan Lagerström (research)
Lantbrukarnas riksförbund, LRF	http://www.lrf.se	The Federation of Swedish Farmers – LRF – is an interest and business organisation for the green industry with approximately 170,000 individual members. Together they represent some 90,000 enterprises, which makes LRF the largest organisation for small enterprises in Sweden
Svebio	http://www.svebio.se/	The Swedish Bioenergy Association (Svebio) was founded in 1980, after the oil crisis in 1979. Is has today around 300 members, most of them enterprises active in producing or providing biofuels or using biofuels on a larger scale

2.6.6 Advanced technologies of relevance for improved biorefineries developed in the research community, and biorefinery-relevant expertise.

*Funding, technologies and expertise***.** The growing realization of the importance of the bioeconomy has resulted in several funding opportunities, research clusters and innovation actions (Table 29) involving thermochemical as well as biochemical routes for the upgrading of biomass. As a consequence, research related to the bioeconomy has increased significantly at several Swedish universities and research institutes. Research related to use of biomass and biorefining technologies is broad and interdisciplinary, with increasing overlap between chemical engineering, biotechnology and material sciences. Schematically it is possible to divide the research into processing of macromolecules (cellulose, hemicellulose and lignin), characterization of the same, and use of biomass for production of smaller molecules (via thermochemical and biotechnological processes) (VR, 2014). Traditional fibre technologies often include characterization of fibre, transport and fractionation of suspensions, drying and separation technology. These technologies are now complemented by selective degradation and modification (focusing on the sugar platform) for production of biobased chemicals (which is a fast expanding field), as well as the characterization of other compounds from the material, including lignin and other smaller natural products.

Sweden has a long and successful research history in the field of biomass conversion, with research spread among many academic institutions with slightly different research profiles. The universities most frequently mentioned in collaborations with industry are according to Mossberg, 2013: Lund University (LU), the Royal Institute of Technology (KTH) and Chalmers University of technology.

Lund University (LU/LTH) has longstanding established strength in industrial biotechnology (pretreatment, enzymatic and microbial conversions) for biobased energy, chemicals and food and feed products.

At the *Royal Institute of Technology (KTH)* there are likewise strong and longstanding links to wood research.

Chalmers Institute of Technology is a newer player in more applied industrial biotechnology, but has significantly increased research in this field, for example via the large Wallenberg Wood Science Center together with KTH.

Apart from these universities, there is a strong link between *Karolinska Institute/Uppsala University* on research on pharmaceuticals, and between *Umeå, Luleå* and *Swedish Agricultural University* on forestry related products. Karlstad University and "Mittuniversitetet" have also documented activities in the same field. In this context, the research cluster "Bio4Energy" is worth mentioning: Bio4Energy is a cluster including Umeå, Luleå and the Swedish Agricultural University as well as Innventia, SP/Processum and a number of industrial players (see www.Bio4Energy.se for a complete list of members) focusing on biomass conversion via gasification and biorefining.

Innovations and development close to the applications is driven for example by the research institute *Innventia*, which has a close connection to the forest industry. The *Swedish Technical Research Institute (SP)* has also initiated large efforts in the field and for example taken over 60% of the Processum research cluster (see also Table 23). Recently, the large strategic innovation area, "*Bioinnovation*", was also started (see home page at www.bioinnovation.se for participating organizations) after evaluation of research agendas selected via a call from the funding agency, Vinnova. This resulted in large funding in the innovation sector related to biomass conversions (with the main focus on forest biomass).

Among the funding organizations, the funding initiatives from *Formas* have a current focus on biomass utilization, ranging from calls on primary production to calls aimed at processing (summarized in the strategic agenda: http://www.formas.se/sv/Forskning/Formas-Publikationer/Rapporter/Forsknings--och-innovationsstrateg-for-en-biobaserad-samhallsekonomi1/). This agenda considers not only the forest and agricultural resources but also highlights the increased need of research for better utilization of marine resources. Thus far, a relatively large intiative on macroalgae farming for example has been funded (Seafarm, www.seafarm.se, involving KTH, Chalmers, Gothenburg University, Linné University and Lund University).

More technology-driven calls of importance have also been launched by *Mistra* (e.g. including a current call on bioplastics) and *SSF* (with a recent focus and large calls on biological conversions and generic technologies for biomass conversion and bioeconomy).

Table 29: Examples of funding agencies, research institutes and academic institutions acting to promote the bioeconomy

Organisation	Location	Type	Home page
Lund University (LU), including complete engineering faculty (LTH)	Lund	Academic institution	www.lu.se (www.lth.se)
Royal Institute of Technology (KTH)	Stockholm	Academic Institution	www.kth.se
Chalmers Institute of technology	Gothenburg	University foundation	www.chalmers.se
Swedish Agricultural Univeristy (SLU)	Spread at several locations in Sweden	Academic Institution	www.slu.se
Karolinska Institute (KI)	Stockholm	Research Institute (focus on pharmaceuticals)	www.ki.se
Uppsala University (UU)	Uppsala	Academic Institution	www.uu.se
Umeå University (UmU)	Umeå	Academic Institution	www.umu.se
Luleå Technical University (LTU)	Luleå	Academic Institution	www.ltu.se
Karlstad University (KaU)	Karlstad	Academic Institution	www.kau.se
Mittuniversitet (MiUn)	Härnösand, Sundsvall, Östersund, Örrnsköldsvik	Academic Institution	www.miun.se
Gothenburg University	Gothenburg	Academic Institution	www.gu.se
Linnéuniversitetet (LnU)	Växjö, Kalmar	Academic Institution	www.lnu.se
Innventia	Stockholm	Research Institute	www.innventia.se

Organisation	Location	Type	Home page
Swedish Technical Institute (SP)	Several places	Research Institute	www.sp.se
SP/Processum	Örnsköldsvik	Research Institute	www.processum.se
Skogforsk	Uppsala, Ekebo, Sävar	Research Institute	www.skogforsk.se
Swedish Research Council (Formas)	Stockholm	Funding Agency	www.formas.se
Swedish innovation agency (Vinnova)	Stockholm	Funding Agency	www.vinnova.se
The Swedish foundation for strategic environmental research (Mistra)	Stockholm	Funding Agency	www.mistra.org
Swedish foundation for strategic research (SSF)	Stockholm	Funding Agency	www.stratresearch.se
Energimyndigheten (STEM)	Stockholm	Funding Agency	www.stem.se

An example of an academic organization with a focus on biomass conversion

Lund University serves as an example for illustrating in more detail the expertise available at one of the academic institutions with longstanding experience in several fields of biomass conversion. Lund University has established competence and many active research groups in the field of industrial biotechnology, agricultural biotechnology and pretreatment technologies, related to biomass conversion, with a special focus on the sugar platform and more recently also lignin-based compounds (see, www.lth.se/biorefinery). In addition to this, the institution also focuses on environmental factors related to biomass conversions (www.miljo.lth.se), and research related to political science and the innovation climate for implementation of the bioeconomy (IIIEE, www.iiiee.lu.se, and Circle www.circle.lu.se).

With regard to technological experience, biotechnology (www.biotek.lu.se, Dept of Chemistry) and chemical engineering researchers (www.chemeng.lth.se) have focused on work related to industrial biotechnology since the 1980s, acquiring significant experience and competence in this area. As a further strengthening step, researchers active in these fields at Lund University have clustered in a network organization, supported by *Region Skåne* (Lund University Biobased Industry Center, LUBIRC at www.lth.se/biorefinery), connecting valuable competences in this field. Biofuel production is another strong research field, and researchers working in this area can be found in the LU-Biofuels- network (www.lubiofuels.org, supported by LTH).

Examples of research platforms include:

- Pretreatment development (chemical engineering, www.chemeng.lth.se), resulting in technologies for efficient use of wood chips and straw for ethanol conversion by yeast.
- The genetic engineering and biocatalysis platform (Biotechnology, www.biotek.lu.se , Applied Biochemistry www.tbiokem.lth.se at the Dept Chemistry and Immuntechnology www.immun.lth.se) has for example led to spin-off companies related to enzymatic production of surfactants (Enza Biotech AB, via research at Biotechnology), novel enzymatic tools for analysis, Genovis (research at the Dept of Pure and Applied Biochemistry) and novel pharmaceutical protein tools (Alligator Biosci AB, via research at the Dept of Immuntechnology).
- Microbial production based on the sugar platform, for example leading to technologies in bioethanol production by yeast cells (research at the Dept of Applied Microbiology, www.tmb.lth.se), and Biogas production (research at the Dept of Biotechnology, www.biotek.lu.se).
- Separation and recovery technologies (chemical engineering, www.chemeng.lth.se), utilizing membrane based technologies.
- In addition to technology development, the university also has a focus and competence in environmental systems studies (www.miljo.lth.se), innovation system studies (www.circle.lu.se) and studies of the political climate for the bioeconomy in Sweden (www.iiiee.lu.se).

To support these structures, funding is sought from both Swedish and International funding agencies, and the European research programs (e.g. EU Horizon 2020) are important contributors in carrying the research forward.

The need to educate future students in issues related to sustainable development has been addressed for many years through all the programs given at the engineering faculty. Courses in the field of sustainable development are thus required for completing the program (see link to education program in Biotechnology at: www.student.lth.se/fileadmin/lth/utbildning/studiehandboken/14_15/B_Uplan_14_15.pdf).

Other mapping activities

In this report, we have made an effort to map academic institutions, research institutes and industries from relevant sectors (as holders of relevant infrastructures applicable to the new bioeconomy), and to give an indication of the number of available organizations and degree of competence in Sweden that are crucial for development of the bioeconomy. *Please note that due to the time frame of this reporting work, the list is not complete. It should also be highlighted that there are other ongoing activities in this field, concerning: Mapping of relevant new opportunities* for bio-conversion technologies and products (for example the ongoing project "Kartläggning av nuläge och möjligheter för bioprocesser integrerade i bioraffinaderikoncept", funded by the strategic innovation area Bioinnovation, www.bioinnovation.se).

2.6.7 The status of Bioeconomy research in Sweden including links to official strategies

Sweden has a national *research* and *innovation* strategy, formulated by the Swedish research council Formas (http://www.formas.se/Forskning/Formas-Publikationer/Swedish-Research-and-Innovation-Strategy-for-a-Bio-based-Economy/). There is not yet a national bioeconomy panel in Sweden, but such a panel has been proposed in the above mentioned research strategy. Thus far, the Ministry for Rural Affairs and the Ministry of Enterprise & Energy have put bioeconomy on their agendas. (Dr. Stefan Källman, Ministry for Rural Affairs (stefan.kallman@gov.se) and Dr. Jan Svensson at the Research Council Formas (jan.svensson@formas.se) are considered as "contact point") (JCR-SCAR, 2014).

Funding related to biomass utilization has significantly increased in Sweden during the last years (not only due to the action of Formas, but also other funding agencies). It is noteworthy, however, and also highlighted by Mossberg, 2013, *that there are no major research programmes or foundations connected to the chemical industry, corresponding to the way they are connected to the energy sector, the forestry industry or iron or steel industries*. Despite the increased funding, there is a tendency towards focusing funding more on general utilization of large biomass streams than on biobased product technologies, which may result in slower development of novel concepts. Exceptions to these trends include a recent call from SSF, focusing on technologies instead of a specific resource.

Sweden does not have one specific agency responsible for the bioeconomy. Instead of a single agency, Sweden has a broad range of agencies and institutions that collect applicable and relevant data (see for example funding agencies listed in Table 20). At the Nordic level (Nordic Council of Ministers) different projects are ongoing. The Icelandic Chairmanship for NCM during 2014 has a Nordic bioeconomy as one of their priorities (NordBio, www.norden.org, http://www.mfa.is/foreign-policy/nordic-cooperation/nordic-council/icelands-presidency-2014-/projects/nr/7880). Among the different industrial sectors relevant for the bioeconomy in Sweden, it is only the forestry area that has a written policy (http://www.forestindustries.se/i_fokus_-_startsidenotiser_1/the-forest-industry-––the-driver-for-a-sustainable-bioeconomy), and the field where implementation is strongest is bioenergy, where Sweden is in an outstanding position (http://www.government.se/sb/d/574/a/123466).

In addition (and as exemplified in the specific example concerning Lund University above), the Bio-economy is an integrated part of the education at the technical universities (e.g. LTH, KTH and Chalmers), as well as at the Swedish University of Agricultural Sciences.

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2.7 Bioeconomy in Denmark

Lene Lange, Technical University of Denmark (before 1 June Aalborg University), Denmark and Jane Lindedam, BioValue SPIR Platform Manager, University of Copenhagen, Denmark and other relevant stakeholders

2.7.1 The status of the bioeconomy in Denmark

The Danish Government has appointed a National Bioeconomy Panel, consisting of members from leading companies, industry associations, researchers, representatives from regions, labor union and NGOs, including representatives from in all five Danish ministries (http://agrifish.dk/fileadmin/user_upload/NaturErhverv/Filer/Tvaergaaende/Biooekonomi/Fact-sheet_The-National-Bioeconomy-Panel.pdf).

The most prominent task of the Bioeconomy Panel is to provide opportunities for concrete actions, ranging from primary production through processing to consumption, which can promote the sustainable bioeconomy in the short and long term. In the initial phase, the Bioeconomy Panel must focus on how the supply of affordable and sustainable biomass can be increased, since this is considered a key prerequisite for the promotion of bio-economy. The Bioeconomy Panel's work must be seen in light of the activities that promote research and market maturity within the bioeconomy (http://naturerhverv.dk/fileadmin/user_upload/NaturErhverv/Filer/Tvaergaaende/Biooekonomi/Kommissorium_Det-Nationale-Biooekonomipanel.pdf).

In the first statement from the National Bioeconomy Panel in September 2014, "Denmark as growth hub for a sustainable bioeconomy", the following benefits of developing the bioeconomy were identified:

- Lessen our dependence on fossil fuels and raw materials.
- Reduce our burden on the environment and climate.
- Create economic development and new jobs, including in rural districts.
- Increase resource efficiency (better utilisation of raw materials).
- Boost technology exports and competitiveness.
- Enhance value creation by getting more or more valuable products out of the raw material.
- Foster the recycling of nutrients (including, for instance, phosphorus).

- Complement food production and advance sustainable crop cultivation.
- Contribute to nature preservation, e.g. by harvesting biomass from river valleys (cited from: http://agrifish.dk/fileadmin/user_upload/NaturErhverv/Filer/Tvaergaaende/Biooekonomi/Statement_Sept2014_Denmark-as-growth-hub.pdf).

2.7.2 Available and accessible biomass feedstocks and prioritized value chains from biorefineries

In Denmark the available resources for developing the bioeconomy are biomass from agriculture, forestry and fisheries, as well as a variety of waste streams from the food industry, shops and restaurants, and private households. In Table 30 below lists the resources available for utilization. For straw the utilization level is approximately one third of the available biomass, and for animal manure the level of utilization is approximately 5%.

Table 30: Total biomass resource for potential non-food exploitation

Biomass	Total Biomass resource	Exploited for energy in 2009
Straw from cereal	2.69	1.34
Straw from rape	0.46	0.10
Straw from seed grass	0.59	0.15
Energi wood (willow and poplar)	0.04	0.04
Rape oil for energy	0.13	0.13
Animal manure	3.59	0.18
Small forests, wind breaks and gardens	0.70	0.70
Existing forest (2010)	0.93	0.93
Drymatter total (mio. T)	9.02	3.56

Note: Adapted from: Jørgensen *et al*. (2013).

Note:: Million tonnes dry matter and biomass exploitation in 2009, assuming that there is no changes in cropping systems, harvest technology and food production. Straw for feed and litter is subtracted from the potential straw resource.

In "The + 10 million tonnes study" (Gylling *et al*., 2013, http://research.ku.dk/search/?pure=files%2F47425822%2FTimioplanUKnet.pdf) it is concluded that it is possible to increase the available biomass by 10 million tonnes per year, with no reduction in food production, no expansion of farmland, and no adverse effects on the environment. Some of the instruments for this increase in biomass production weres: utilizing cereal species producing 15% more straw; increased recovery of straw; replacing oilseed rape with sugar beet; allowing fertilization of wetland areas; replacing part of the area under grain with sugar beet; better utilization of forest resources; and not the least better utilization of light by extending the growing season.

2.7.3 Mapping of accessible public and private biorefinery-relevant infrastructures in Denmark

Table 31: Mapping of accessible public and private biorefinery-relevant infrastructures in Denmark

Biorefinery	Location	Biomass in focus	Biorefinery, Methodology	Product(s) in focus
Aalborg University	Aalborg/ Copenhagen		Continuous Hydrothermal Liquifaction (HTL) pilot plant for multiple organic input streams (eg lignocellulosics, grasses, organic residual streams)	Liquid biofuels, refinery bio-intermediates, petrochemical bio-equivalents, fuels from CO2
Aarhus University	Foulum	Lignocellulose	Hydrothermal conversion pilot plant (HTL) – continuous with energy recovery	Bio- crude oil and biobased chemicals (bioenergy)
Aarhus University	Foulum	Perennial grasses and other green biomass	Green biorefinery for production of protein enriched animal feed from green clover/grass	Animal feed
Aarhus University	Foulum		Biogas pilot plant including biogas to SNG upgrading	Bioenergy, energy storage
Aarhus University	Aarhus		Lipid extraction and conversion	Functional lipids and fuels
Agrotech	Aarhus		Assistance in prototype development and proof of concept. Harvest techniques and storage trials	
Amager Resouce Center (ARC)	Copenhagen	Household waste	Facilities for collaborative development of new ways of upgrading organic waste streams	Bioenergy, construction materials, Recycling of plastics and metals
University of Copenhagen	Copenhagen	Lignocellulosic biomass	High throughput pretreatment and enzymatic hydrolysis systems (HTPH-systems) for screening of lignocellulosic biomass for enzymatic saccharification	Sugar platform, Bioenergy
University of Copenhagen	Copenhagen	Green biomass	High throughput amino acid analysis based on microwave assisted protein acid hydrolysis for screening of protein quality	Protein platform, proteomics, genomic selection
Dong Energy Inbicon Biorefinery (Temporarily closed)	Kalundborg	Wheat straw	2nd generation Bioethanol plant pilot plant	Bioenergy

Biorefinery	Location	Biomass in focus	Biorefinery, Methodology	Product(s) in focus
Danish Technological Institute (DTI)	Taastrup/ Aarhus		Up-scaling facilities for pre-treatment, storage stability and biomass conversion product development	Bioenegy, biochemical, biomaterials, food and feed ingredients
Technical University of Denmark (DTU) Center for Bioprocess Engineering (BIOENG)	Kgs. Lyngby		Pretreatment pilot plant; Upscaled fermentation bioreactors	Danish Technical University (DTU) Center for Bioprocess Engineering (BIOENG)
Technical University Of Denmark (DTU) Center for Bioprocess Engineering (BIOENG)	Kgs. Lyngby		GMO Fermentation Pilot Plant	Danish Technical University (DTU) Center for Bioprocess Engineering (BIOENG)
European Protein, Aarhus University and pig farmer Henrik Mols	Jelling	Rape, Sunflower, favabean	Demonstration plant	Fermented protein feed
MEC Maabjerg Energy Concept	Maabjerg	Wheat straw and household waste	Full scale 2nd generation Bioethanol plant	2nd generation bioethanol and other bioenergy products
N.C. Miljø	Nyborg	Biowaste	Full-scale plant Supermarket waste is the main input today, but SDU is running experiments with household waste	Bioenergy (biopulp for biogas)
Roskilde University	Roskilde	Lignocellulosic biomass	Calorimetric equipment platform	Enzyme cocktails for deconstruction of agricultural residue
University of Southern Denmark (SDU)	Odense	Lignocellulosic and waste biomass	Yellow and Green Biorefinery Biogas pilot plant	Bioenergy
University of Southern Denmark (SDU)	Odense		Reactive crystallization for phosphorus recovery	Phosphorus
University of Southern Denmark (SDU)	Odense		Crystallization for natural products isolation and purification	Natural products with pharmaceutical activity
University of Southern Denmark (SDU)	Odense	Vegetable oils and fats. Straw degradation	Biodiesel and second generation bioethanol production Process simulation of biofuel refineries	Biofuels

Biorefinery	Location	Biomass in focus	Biorefinery, Methodology	Product(s) in focus
University of Southern Denmark (SDU)	Odense	Usage of waste from the fishery industry	Protein and pigment recovery from fish and shrimp waste streams. Extensive experience with membrane processes for product separation	Food additives
University of Southern Denmark (SDU)	Odense	Extraction and purification of secondary metabolites from algae and plants	Extensive experience with extraction and separation processes for product separation of secondary metabolites like pigments, flavonoids, aromas, polysaccharides etc.	Natural food additives and l health products
University of Southern Denmark (SDU)	Odense	Separation of animal manure	Extensive experience with membrane processes for separation of fertilizer fractions from animal slurry	Liquid and solid fertlizers
Unibio A/S Danish Technical University (DTU)	Odense Kgs. Lyngby		Large-scale demonstration plant Production of protein from *M.capsulatus* with methane (and a nitrogen source) as the main input	Protein for animal feed

Value Chains

The National Bioeconomy Panel has identified a number of value chains, some of which have already been implemented, and some that are only at a very early stage and will need further development (Table 32).

Table 32: Possible promising value chains as identified by the National Bioeconomy Panel

Biomass	New value chain	Existing use	What is needed to develop the value chain
Blue Biomass: Fish discard and fish waste	Food ingredients, protein rich feed, fish oil for human consumption	Low value animal feed, biogas	Research (development of enzymes etc.) Launch of commercial-scale ventures
Blue Biomass: Macro algae	Cosmetics, food ingredients, food, health products, polymers	Is only sporadically used	Research and development
Green Biomass: Grass, Clover and other plants and plant parts	Extraction of protein (for animal feed) and possibly also high value produce (such as vitamins, food ingredients), utilization of waste rich in fibers	Rough feed, biogas or fertilizer for organic crop cultivation	Breeding of new strains more capable of fixing nitrogen and hence with a higher protein content and quality More types of biomass to be used in order to ensure steady year-round supplies Development and upscaling of industrial plants for production of animal feed protein and high value products Development of competitive methods for conversion of fibre contents into energy and/or other uses Difficult for businesses to bring about on their own, need to partner up with other actors in society

Biomass	New value chain	Existing use	What is needed to develop the value chain
Green Biomass: Alternative protein crops	Protein for, for instance, animal feed from alternative protein crops, such as clover, grass and broad beans	Animal feed	There is a need for public-private partnership to support the development and cultivation of alternative protein crops, when this is unprofitable on business terms
Yellow Biomass: Straw, other cellulosic by-products	Biorefining, conversion into sugars and lignin, which can be used as raw materials for production of second generation biofuels and biomaterials	Combustion, deep bedding, ploughing-in	Creation of a market for second generation bioethanol Points to be addressed and potentials: There is a need for support for production of liquid fuels from straw Biofuels are exempted from the carbon tax, but this does not make any distinction as to how much they contribute to reducing CO2 emissions or whether they are based on byproducts and waste Development of more high value produce derived from C5 and C6 sugar polymers
Brown Biomass: Wood	Production of gas, possibly including upgrading of gas to natural gas through gasification of wood in local plants	The biomass is not produced to its full extent Burning of wood chips	There must be sales outlets for the biogas, also in the short term, for instance for burning (until it can be used for high value produce)
Waste from meat production	Upgrading of meat protein and energy resource	Meat and bone meal, animal feed	New food regulation required Development of processes and products as well as regulatory investigations and approvals
Waste from dairy	Whey protein used for various food products	Some of the whey is	Generic research to support commercial product development undertaken by businesses themselves, supplemented by efforts in research and development
Unsorted household refuse	Biogas and new materials from household refuse: through the "REnescience" process, a bioliquid is made, which may be used for microbial production of materials or biogas	Direct burning	Regulation is currently preventing the recycling of nutrients, since degassed material cannot be taken into the field Research and development regarding new materials made from the REnescience bioliquid
Protein-rich animal feed	Improved livestock feed/protein absorption by enhancing bioaccessibility and specificity of, for instance, protein in the feed	Animal feed	It is difficult for businesses to take on the development task, need to partner up with other actors in society

2.7.4 The National Bioeconomy Panel: Obstacles identified and Recommendations made[1]

The National Bioeconomy Panel has identified a series of obstacles for direct implementation of the above value chains (http://naturerhverv.dk/fileadmin/user_upload/NaturErhverv/Filer/Tvaergaaende/Biooekonomi/Udtalelse_sept2014_Danmark-som-vaekstcenter.pdf):

- Lack of market pull.
- Lack of political objectives.
- Restrictive regulation.
- Insufficient sustainability criteria.
- Difficulty of moving from research to pilot projects and from pilot to full-scale (cited from: http://agrifish.dk/fileadmin/user_upload/NaturErhverv/Filer/Tvaergaaende/Biooekonomi/Statement_Sept2014_Denmark-as-growth-hub.pdf).

The immediate recommendations from The Panel were as follows:

- The Bioeconomy Panel calls on the government to work intensively for the establishment of an advanced, integrated, industrial-scale biorefinery in Denmark. One requirement for moving from demonstration to industrial production is demand for biobased alternatives to products that are currently made using fossil raw materials. Such demand can be created both politically and through the market.
- The Bioeconomy Panel acknowledges that special barriers obstruct the development of new industrial bioeconomic value chains – and of a few existing ones, such as biogas. Therefore, the Bioeconomy Panel will continuously identify regulatory barriers to bioeconomic development and inform the government thereof, so that this can be analysed in more detail and serve to substantiate decision-making in future adjustment of framework conditions in this domain. In this regard, the government is called upon to look into whether the

[1] Additional specific recommendations for actions needed to stimulate the development the yellow biorefinery have already been published (http://naturerhverv.dk/fileadmin/user_upload/NaturErhverv/Filer/Tvaergaaende/Biooekonomi/Biooekonomipanelets_anbefalinger_ved_anvendelse_af_gul_biomasse.pdf). Recommendations from the National Bioeconomy Panel for the green biorefinery, the blue biorefinery, and biorefineries for upgrading waste streams of agroindustry and organic municipality waste, are expected within a few months.

incentives structure underpins the development of new industrial bioeconomic value chains, or whether, for instance, further support for technological development is needed.

- The Bioeconomy Panel recommends that more partnerships be established with the participation of public authorities, private sector actors and knowledge centres. These may focus on, for instance, attracting capital (including EU funds and other financial support) for the development of technologies. The government, relevant authorities, industrial organisations, the financial community and businesses can also – based on the aforementioned positions of strength – forge partnerships with the aim of attracting foreign capital in order to ensure continued development and the establishment of bioeconomic value chains in Denmark.
- The Bioeconomy Panel calls on the ministries involved to cooperate and coordinate closely in relation to bioeconomic development, and to keep the Bioeconomy Panel informed of such collaboration.
- The Bioeconomy Panel calls on industrial organisations, knowledge centres and NGOs to support relevant public authorities with knowledge and ideas for criteria capable of promoting public purchases of sustainable bioeconomic products (cited from: http://agrifish.dk/fileadmin/user_upload/NaturErhverv/Filer/Tvaergaaende/Biooekonomi/Statement_Sept2014_Denmark-as-growth-hub.pdf).

Further publications from The National Bioeconomy Panel include

Factsheet on Sustainability (http://naturerhverv.dk/fileadmin/user_upload/NaturErhverv/Filer/Tvaergaaende/Biooekonomi/Faktaark_Baeredygtighed.pdf).

Factsheet on current production of straw (http://naturerhverv.dk/fileadmin/user_upload/NaturErhverv/Filer/Tvaergaaende/Biooekonomi/Faktaark_-_Vaerdikaeder_for_halm.pdf).

Background brief for Factsheet on current production of biomass (http://naturerhverv.dk/fileadmin/user_upload/NaturErhverv/Filer/Tvaergaaende/Biooekonomi/IFRO_-_Baggrundsnotat_om_halm_og_andre_celluloseholdige_biprodukter.pdf).

Case description on uses of yellow biomass (http://naturerhverv.dk/fileadmin/user_upload/NaturErhverv/Filer/Tvaergaaende/Biooekonomi/Casebeskrivelser_-_Anvendelse_af_gul_biomasse.pdf).

2.7.5 Listing of bioeconomy relevant businesses with biorefinery-related infrastructures incl biological production

Table 33: Infrastructures of relevance for biorefinery technologies and bioeconomy business in Denmark

Biorefinery	Location	Biomass used	Biorefinery, Methodology	Product(s)
Companies				
Amager Resource Center (ARC) (REnescience technology for treatment of organic household waste) Participants DONG Energy, Copenhagen municipality, Biofos, DTU and Copenhagen University)	Copenhagen	Household waste (new plant can process up to 20 ton/hour)	Enzymatic separation of household waste in usable fractions	Biogas, Heat, construction materials Recycling of plastics and metals
Arla	Viby J	Side streams from dairy products	Commercial scale biorefinery production upgrading all side streams from dairy products	Commercial scale biorefinery production upgrading all side streams from dairy products
BHJ Pet Food	Graasten	Animal byproducts	Physical, thermal and enzymatic conversion	Pet food, Mink/Fur Food
Billund Biorefinery	Billund	Household waste, waste water, Organic waste from industry and agriculture	Thermal hydrolysis	Organic fertilizer, Phosphorous fertilizer, Biogas
Biogasol	Ballerup			Technology and supporting services to first and second generation biofuels as well as biochemicals developers and manufacturers. Carbofrac® Pretreatment Pentocrobe® Fermentation Biochemical Processing
Carlsberg		Barley etc. Wastewater from brewing of beer		Commercial scale biological production, brewing Biogas
Chr Hansen	Hørsholm	Agricultural products	Biological production	Ingredients, starter culture's and enzymes primarily for food processing
CP Kelco	Lille Skeensved	Seaweed, citrus peel, locust beans	Microbial fermentation, separation and recovery	Pectin, Carrageenan and Refined LBG (remains from pectin production used as cattle feed supplement, and the residue from carrageenan production is used as fertilizer)

Biorefinery	Location	Biomass used	Biorefinery, Methodology	Product(s)
Daka ecoMotion	Løsning	Animal byproducts (fat) and organic waste (used deep frying oil)	Physical and chemical conversion	Biodiesel, glycerin and potassium sulphate
DAKA Refood	Løsning	Food waste, used frying fats and frying oils	Physical and chemical conversion	Feed, fertilizer, Biogas, Phosphorous, Biodiesel
Daka SecAnim	Randers	Slaugther house discards, dead life stock	Physical and chemical conversion	Organic fertilizer (bone meal), Hides, and energy
Daka Sarval	Løsning, Lunderskov	Foodgrade pig products, animal byproducts and blood	Physical and chemical conversion	Food and feed products
Danisco/Dupont	Haderslev, Brabrand, Tønder, Copenhagen, Grindsted	Agricultural products,	Biological production, fermentation, separation and recovery	Commercial scale for ingredients and enzymes Food ingredients, pet food and dietary supplements
Danish Crown Ingredients,	Randers, Aabybro	Byproducts from slaughterhouse	Commercial scale biorefinery production upgrading all side streams from slaughterhouse products	Functional and high quality (high BCAA) hydrolysates raw materials for Pharma, animal Feed and petfood
DLF Trifolium	St. Heddinge, Roskilde	Grass and Clover	Plant breeding for specific qualities	Crop plants with specific qualities
DONG (INBICON technology, REnescience);	Skærbæk, Kalundborg	Lignocellulosic biomass	Biological conversion	2nd generation bioethanol and valuable products for renewable biofuel and biochemical products.
Emmelev Mølle A/S	Emmelev	Rapeseed oil	Biodiesel production	1st generation biodiesel production
European Protein	Bække/ Jelling	Rape, Sunflower, favabean	Fermentation	Dried lactic acid fermented protein feed primarily for pigs
Fermentation Experts	Bække	Rape, Sunflower, favabean, food byproducts	Fermentation	Fermented protein feed
Grønt center (Merged with Agrotech)	Holeby			Innovation within food- and agroindustry, plant production
Hamlet protein	Horsens	Soybean	Fermentation, conversion and separation	Safe Proteins or Animal feed (reduced anti nutritional factors)

Biorefinery	Location	Biomass used	Biorefinery, Methodology	Product(s)
Herrens Mark	Nr. Åby	Dandelion, Red Clover	Lactic acid fermentation	Food supplements, health products
KMC	Karup	Potatoes, Tapioca	Physical separation and precipitation	Ingredients, Potato protein
MEC Måbjerg Energi Center	Maabjerg	Wheat straw and household waste		2nd generation bioethanol and other bioenergy products.
Novozymes	Kalundborg	Enzyme production	Fermentation	Biological production, commercial scale for ingredients and enzymes
Novozymes/Novo Nordisk Biogas	Kalundborg	Waste water from enzyme production	Fermentation on wastewater from enzymeproduction	Biogas, as well as products for improved wastewater treatment, and increased production of Biogas from wastewater
Renew Energy A/S	Svendborg			Development of Biogas plants
Terranol	Kgs Lyngby			Yeast strains developed for 2nd generation bioethanol production
Xergi	Støvring			Development of tailored Biogas plants

2.7.6 List of Universities and organizations in Denmark with interest in developing the bioeconomy

Table 34: List of Universities and organizations in Denmark with interest in developing the bioeconomy

Organization	Location	Type	Focus areas	Home page
Aalborg University	Aalborg	Academic Institution	Development of processes for Biomass conversion for production of animal feed, bioenergy, biochemicals, biomaterials, healthy feed and food ingredients	www.aau.dk
Aarhus University	Aarhus	Academic Institution	Value added products, bio-energy, lipids, biogas, biogas upgradation, protein refining, Synergy in biorefining, biomass production	www.au.dk
Danish Technical University	Kgs. Lyngby	Academic Institution	Development of processes for Biomass conversion, product separation and product development; for production of bioenergy, biochemicals, biomaterials, healthy feed and food ingredients	www.dtu.dk
Roskilde University	Roskilde	Academic Institution	Characterization of enzyme performance; design of cellulytic enzymes	www.ruc.dk

Organization	Location	Type	Focus areas	Home page
University of Copenhagen	Copenhagen	Academic Institution	Optimisation of biomass, plant breeding and growth (soil, nutrients), biomass supply, biomass characterisation, pre-treatment, hydrolysis and fermentation. Biofuels, Proteins and biochemicals	www.ku.dk
University of Southern Denmark	Odense	Academic Institution	Development of industrial extraction and separation processes for high value secondary metabolites, fertilizers, proteins and biofuels, piolot scale biogas reactors	www.sdu.dk
Agrotech	Taastrup	Independent R&D institute		www.agrotech.dk
Danish Technological Institute (DTI)	Aarhus/ Taastrup	Independent R&D institute	Biomass and Biorefinery, pretreatment, enzymatic hydrolysis, fermentation, biomass analyses and chemical characterization, logistics, pilot scale equipment for biorefinery, biomolecule extraction, animal feed production, and solid biofuel	www.teknologisk.dk
BIOPRO	Kalundborg	Network / cluster		
Biorefining Alliance	Frederiksberg	Network / cluster		www.biorefiningalliance.com
CLEAN	Copenhagen	Network / cluster		www.cleancluster.dk
Danish Food Cluster	Aarhus	Network / cluster		www.danishfoodcluster.dk
Dansk Biotek	Copenhagen	Network / cluster		www.danskbiotek.dk
Ingrediensforum	Copenhagen	Network / cluster		www.ingrediensforum.di.dk
DAKOFA	Copenhagen	Network / cluster		www.dakofa.dk
Fonden Teknologirådet	Copenhagen	Network / cluster		www.tekno.dk
National Bioeconomy Panel	Copenhagen	Network / cluster		http://naturerhverv.dk/tvaergaaende/biooekonomi/#c31679
SEGES	Aarhus	Network / cluster		www.seges.dk

2.7.7 Major bioeconomy and biorefinery relevant research and innovation projects

The below list is from https://biobs.jrc.ec.europa.eu/sites/default/files/generated/files/country/National%20Bioeconomy%20Profile%202014%20Denmark.pdf, and supplemented with further information:

- INBICON http://www.inbicon.com/en & REnescience http://www.renescience.com/en
- BioBase – a research initiative of the University of Aarhus with four research platforms (green biomass, green protein, HTL, societal, environmental, ecological and economic assessments) http://dca.au.dk/forskning/bioraf/forskningsinitiativer/biobase/
- Maabjerg Energy Concept: The Maabjerg Energy Concept envisions creating a comprehensive, sustainable energy solution, based on local and CO2-neutral raw materials, by using the latest technologies. The project merges several energy supply objectives (CHP, Biogas, Bioethanol) in a holistic system concept, where the synergy between the individual solutions is used optimally and highy effectively through the utilisation and alignment of energy streams between the individual plants, http://www.maabjergenergyconcept.eu/
- Biomass for the 21st century: Integrated biorefining technologies for shipping fuels and biobased chemicals (B21st). A platform which brings together leading players within the sustainable use of biomass. The platform provides a framework for the parties' joint research, aimed at developing specific sustainable solutions for the production of building blocks for chemicals and biobased fuels for the global shipping industry, http://news.ku.dk/all_news/2011/2010.12/new-research-platform-paves-way-for-future-bio-based-society/; http://b21st.ku.dk/
- BioValue SPIR: The aim of the BIO-VALUE platform is to make sustainable solutions for biorefining technologies. BIO-VALUE deals with the entire value chain from sustainable biomass production, to separation and conversion into new products. The BIO-VALUE platform has a budget of DKK 160 million to develop new sustainable technologies for upgrading plant material into internationally competitive products. Until 2018, the BIO-VALUE platform will strive to provide leading examples on how to kickstart the biobased economy with sustainable high value products, such as proteins, polymers, and chemical components for industry. The platform is funded under the SPIR initiative by The Danish Council

for Strategic Research and The Danish Council for Technology and Innovation, http://ufm.dk/en/research-and-innovation/funding-programmes-for-research-and-innovation/who-has-received-funding/spir-grant-2012-within-the-bio-based-society-bio-value, http://strategiskforskning.dk/, http://biovalue.dk/

- OrganoFinery: Organic growth with biorefined organic protein feed, fertilizer and energy, http://icrof.eu/Pages/Research/ORG_RDD2_OrganoFinery.html
  The project is developing a new platform for organic growth based on a concept for biorefinery of green herbage to protein feed, fertilizer and energy. The project will deliver solutions to the following key challenges to the organic sector: supply of organic protein feed to monogastric livestock; improved, climate-friendly, and robust crop rotations in areas of low livestock density; better use, efficiency of nutrients; and higher yields.
  Project activities: Identification of the best suited material for biorefinery through cropping trials; harvest and extraction of green leaf protein through fermentation; separation; production, profiling and testing of organic protein feed on poultry; treatment of the residual biomass in a biogas plant for the production of biogas and valuable organic fertilizer; business model development for organic protein feed, fibre material for biogas and for system export; optimizing of the system for upscaling; national and International dissemination:

- BioPro http://www.biopro.nu/ BIOPRO is a Biotech cluster located on Zealand, with a three-pronged partnership structure: industry, universities and a fertile regional business environment.
- Future Cropping: http://www.biopress.dk/PDF/innovationsfonden-investerer-50-millioner-kroner-i-fremtidens-landbrug

It is important to realize that new test facilities are often developed as a joint task between universities and/or research institutes and private companies, with the addition of government funding, in larger projects and platforms, as is the case with BioValue Spir, described below. These infrastructures are then available through cooperations among the respective projects and platforms. Thus joint publicly/privately financed projects and platforms play a very important role in advancing the bioeconomy.

Case: BioValue SPIR, status of significant infrastructures relevant to the bioeconomy in Denmark based on the partners in BioValue SPIR
By Jane Lindedam, Platform Manager BioValue SPIR

A substantial amount of biological material is the basis for an infrastructure on biomass characterization and quality assessment, involving:

- Long-term trials on cropping systems, crop management and fertilizers etc. for optimized sustainable supply of biomass for biorefineries.
- Long-term trials of valuable cultivars for tailoring biomass to biorefineries, genetic collections, archives of biological material for GWSA.
- Hardware and development of a multi-pronged analytical toolbox for high-throughput solutions of biomass assessment e.g. saccharification after pretreatment and enzymatic hydrolysis; fast amino acid analysis in green biomasses based on microwave assisted protein acid hydrolysis; comprehensive microarray polymer profiling (CoMPP) used to characterize carbohydrates and further developed to screen specific lignocellulosic enzymatic activity; substrate-enzyme interaction and water binding capacities of all types of biomass.

A substantial amount of hardware is the basis for spurring the development of infrastructure on pilot- scale bioprocessing, including:

- A new pilot facility for hydrothermal conversion of lignin and other biomass streams has been designed, constructed and assembled at Aarhus University (AU) – Foulum; earlier, a pilot plant had also been established at Aalborg University. The official inauguration of the Hydrothermal Liquefaction (HTL) pilot plant at AU was 22 May, 2015. The facility is unique in flexibility and integration because it contains special features and a modular construction that will allow adaptions to suit a range of processes and conditions. Some design data are: 60l/hr, 300 Bar, 450 °C.
- Construction of a new pilot facility for protein extraction from green biomass at AU-Foulum. The pilot plant will be established during 2015, and methods for protein extraction and characterization will be up-scaled by summer 2016. Characterization of biomass in terms

of biological value (as feed), determination of amino acid content and extraction of proteins are analytical precursors for building the pilot scale plant.
- Various lab to pilot-scale hardware within advanced bioprocessing, including pretreatment of lignocellulosic biomass, membranes for separation techniques, enzymatic processing and fermentation.

BioValue SPIR recommendations: Actions needed to improve infrastructures relevant to the bioeconomy in Denmark

- Demonstration of flexible pressurized unit processes up to 1 kilo scale such as centrifuges, filters, decanter and pressurized reactors to simulate varying bioprocesses. There is a need to reinforce the screening and characterization tools in this step for a better understanding of biomass as a raw material and the biological/chemical processes used for processing. Being able to work at this scale supports the technology transition to pilot and demonstration scale.
- Construction of more pilot- and demo-scale facilities in the form of plants with a focus on pretreatment, protein separation, microbial and enzymatic conversion, hydrothermal processes and product separation, along with access to industrial-scale facilities for integrated bioprocessing.
- Strategies to upgrade existing industrial infrastructures to high-efficient sustainable biorefineries in the short-term, for instance existing power plants, biofuel facilities, oil refineries, pulp/paper industry, and the food industry.
- Strategies on how to enable and accelerate the transitional phase from a largely “black economy” based on fossil carbon to a “green economy” largely based on biobased resources. In other words mapping how biobased value chains can be integrated with the fossil carbon value chains, thus developing and demonstrating the concept of “greening the black economy”.

2.7.8 Bioeconomy relevant Business cases

The following cases are selected to illustrate the possibilities for exploiting the ideas of the bioeconomy. The selected companies have managed to see the options through 1) utilizing resources that were considered as waste or 2) increasing the value of the product by upgrading. It is important to emphasize that these companies are by no means the only ones.

Case1: Daka, Denmark A/S

As part of the SARIA Group, Daka produces quality ingredients for use in food, animal feed and the aquaculture industry, as well as in the energy and agricultural sectors. As raw material for this Daka primarily uses animal byproducts and organic residues.

Dakas' business is divided into four Areas: Daka ecoMotion, Daka ReFood, Daka SecAnim, and Daka SARVAL

In Daka ecoMotion the main focus is on the production of biodiesel from refined animal fats extracted from byproducts from slaughterhouses, or from primary agriculture. Used cooking oil and other oils unsuitable for food production as well as other residual products are also used in the production of Biodiesel

Daka ReFood is involved in collection and recycling of organic byproducts through providing a service solution for supermarkets, food producers, restaurants and other industrial kitchens. The collected food waste is used in the production of fertilizer/phosphorus, biogas and biodiesel.

In Daka SecAnim, animal and other organic byproducts from farms and businesses are collected and reused in the production of fertilisers and CO2 neutral energy. Furthermore, meat and bone meal can be used in the production of cement and building materials, etc. as well as for a CO2-neutral biofuel comparable to wood chips and other biomass.

At Daka SARVAL high quality proteins and fats are produced for animal feed for livestock, pets, fish and fur animals. Further, highly refined functional plasma proteins for both food and feed products are produced.

- Ref: http://www.daka.dk/dk/daka/sonderseiten/hjem/

Case 2: BHJ

BHJ Meats and Byproducts is involved in collection, processing and distribution of animal byproducts and meat blends for use in the food and pet food and feed industries.

BHJ Food produces a wide range of meat cuts for the food industry as well as a variety of ingredients for both food products and pharmaceutical purposes. An example is Pancreas for insulin production, Mucosa and plasma for blood treatment of various kinds, and cartilage for arthritis treatment products.

BHJ Pet food produces a range of dried snacks as well as ingredients to increase the palatability of pet foods, and is involved in collection of poultry byproducts which are processed into either a raw material for mink feeding or ingredients for the production of pet food.

- Ref: http://www.bhj.com/

Case 3: Danish Crown Ingredients
Danish Crown is an international company that produces and markets pork and beef. Since 1989 all slaughterhouses in the Danish Crown group have delivered slaughterhouse waste for the production of biogas.

However, in 2014 a new daughter company was established as DC Ingredients. The aim of this company is to develop processes for converting the waste and side streams from the existing Danish Crown companies into high value products and ingredients. Examples of this could be functional proteins and specific hydrolysates for the food industry, products for the pharmaceutical industry and various ingredients for the feed industry.

- Ref: https://www.mm.dk/danish-crown-satser-staerkt-biologiske-restprodukter

Case 4: Fermentation Expert
Fermentation Experts has developed methods for fermenting vegetable protein crops into easily digestible protein feed. The aim is to be able to replace imported soy protein and fish meal in animal feed with locally grown protein. The fermentation process improves compounds from seed from such as oilseed rape and sunflower crops. Fermented feed products have shown very positive effects on the gut health of monogastric animals due to induction of bioactive lactic acid bacteria.

- Ref: http://www.fermentationexperts.com/

Case 5: Maabjerg Energy Concept
Maabjerg Energy Concept is a consortium consisting of Vestforsyning, Struer Forsyning and Nomi, which together hold 50%, and 50% shared between DONG Energy and Novozymes. The plan is to build a 2nd generation bioethanol plant, a hydrogen production plant and a waste treatment plant. At the same time, the production of biogas by Maabjerg BioEnergy will be increased significantly, just as the biomass-fired cogeneration plant Måbjergværket will be revamped. The aim is to produce 80 million litres (21 million gallons) of bioethanol and about 50 million cubic meters of biogas annually. Part of the biogas produced will

be upgraded to sustainable gas (natural gas). Furthermore, district heating will be produced for 20,000 households, along with electricity equivalent to the consumption of 25,000 households. The goal is conversion of 300,000 tonnes of straw into bioethanol, biogas and energy. In addition, about 800,000 tonnes of biomass (primarily liquid manure) has already been planned for processing at Maabjerg BioEnergy.

- Ref: http://www.maabjergenergyconcept.eu/facts.aspx

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3. Developing the Nordic Bioeconomy – Business needs and opportunities/ Consultancy reporting

Bryndís Björnsdóttir, Matis, Gunnþórunn Einarsdóttir, Matis and Kolbrún Sveinsdóttir, Matis

3.1 Summary of Business needs and opportunities

This survey and analysis was initiated to ensure that the perspectives of the Nordic biorefining industry are incorporated into the NCM funded project; Test Centers for Green Energy Solutions – Biorefineries and Business Needs, which aims at analysing the industries opportunities and challenges, as well as to map operating biorefineries and test centers in the Nordic region. The survey was conducted through structured interviews of 37 stakeholders from within the Nordic biorefinery sector, representing all five Nordic countries, as well as Greenland and the Faroe Islands. The stakeholders were interviewed on their operations, development, and visions for the future, with emphasis on the industries major opportunities and needs and their recommendations for how best to move the sector forward, towards a thriving Nordic bioeconomy.

The Nordic countries have set clean technologies and green growth on high priority and have ambitious plans for replacing oil-based products and to reduce greenhouse gas emissions. Furthermore, the region focuses on greatly strengthening the Nordic bioeconomy, which aims at the sustainable use of natural resources for production and utilization of biological products and processes. Biorefining, which is the process of refining biomass feedstocks into bioenergy and other bioproducts, will play a central role in the Nordic bioeconomy and has been identified as Europe's most promising route to a bio-based industry.

Many biorefinery initiatives have been launched within the Nordic region and there is good focus on utilization of renewable biomass, side streams and waste. The range of processes, applications and products is considerable and growing. The number of participating stakeholders (37) in this survey is believed to give a general good overview of the Nordic biorefining industry, but insufficient to analyse any significant differences between the individual Nordic countries. The surveys stakeholders represented biorefining industries of different sizes, maturity levels and applications, as well as various supporting bodies and organizations. The biorefineries represented in this survey, producing either bioenergy, bioproducts, or both, mostly utilized a range of lignocellulosic- and waste biomasses. The product range was diverse, with specialty chemicals and biofuels being the most commonly produced products, and the main markets being health and pharma, food, and biofuels. The focus among the participating stakeholders was primarily on the sugar and constituent biorefinery platform for refining a range of biochemicals from renewable biomass.

The primary identified opportunities of Nordic biorefineries were biomass availability and potential, the competitive level of R&D, and technology availability and development. The major challenges were not as easily identified, as stakeholder answers were more divided between different categories. However, lack of profitability of bioenergy products, funding difficulties and unsupportive regulatory framework were the most frequently mentioned challenges.

There is a need for a strong co-Nordic biorefining innovation center, which actively supports biorefining industries on various levels, mainly on product-development, testing and registration, funding, marketing, scale-up and the regulatory framework, both within the region and globally. Stakeholders indicated that they required a better overview over the applications and range of products in development and that a feasibility study of applications, products and market needs should be performed for the region.

Research funds have been essential for the initial development of the Nordic biorefining industry but funding for basic research needs to be more long-term and increasingly focused on scale-up of promising applications. There is a challenge to bridge the gap from research and early proof-of-concept to scale-up and commercial demonstration. For that, the Nordic biorefining industry requires large investments in scale-up, demonstration and commercialization. Large-scale demonstration sites suitable for a range of applications are lacking within the region and urgently needed, as well as better utilization and overview of existing test facilities.

Several biorefining applications have successfully completed the demonstration phase and need investments for commercialization. The Nordic biorefining industry needs to gain market experience and to have several large-scale biorefinery operations running for proof-of-concept. The large investments required for these new technologies and applications are at high risk for investors. Therefore, governmental co-investments and initiatives are needed to attract and reduce the risk of private investors. Several of the biorefining products ready for market are bioenergy products, which are low-value products that cannot compete with fossil fuels and will depend on subsidies. Creating strong markets for biorefining products, such and through blending mandates and public procurement, will be important for supporting the industry. However, with subsequent development of higher value bioproducts and increased utilization of the biomass, the sector is believed to become profitable and free of subsidies.

The Nordic biorefining industry needs governmental support, at least in the initial stages, which should mainly be focused at innovative applications and initial scale-up and commercialization setups. Lack of clear and long-term political initiatives, incentives and regulatory framework are currently a major hindrance of investment in the sector. Increased political incentives are needed, through investments in scale-up and commercialization, subsidization of low value biorefinery products, particularly bioenergy products, and increased blending mandates and tax incentives.

To conclude, the Nordic region has great potential in building a strong and versatile biorefining industry and has competitive strength in the field. However, the Nordic region risks falling behind and may lose its competitive strength if actions to improve the industries support network are not taken promptly.

The following sections list the Nordic biorefining industries learning lessons and shared best practices, as well as recommended actions, based on the survey's results.

Learning Lessons and Shared Best Practises

Lessons learned is the knowledge or understanding gained by experience, which has an impact on operations. Lessons learned can lead to best practises of specific techniques, processes and activities, which has proven to be most effective in providing a certain outcome.

Below is a list of major learning lessons and shared best practises of the Nordic biorefining industry, as evident from stakeholder interviews.

These lessons and practices reflect the industries experiences in the developmental-, marketing- and political environment in which it has developed. They can be used to recognize different accomplishments, as well as necessary requirements for improvement.

Lessons learned	Shared best practices
Development of a biorefinery is a time consuming and difficult process	Have patient funding and investors
Thorough basic research and concept formulation is important	Collaborate with various research and support bodies
Biomass and/or product transportation is expensive	Biorefineries need to be strategically located and infrastructure needs to be good
Important to retain intellectual property rights over innovative processes and products	Protect intellectual property with patenting
Multi-stream, flexible biorefineries which produce high value products and/or utilize the biomass to a high degree are important for profitability	Implement multi-product streams, high biomass utilization, and develop high value products from start-up
Development of marketing strategies alongside product development is beneficial	Seek professional marketing support and access marketing research. The regions image can be used as a strong marketing tool
Registration of novel products or compounds is difficult, expensive and time consuming	Seek expert public and private support for product registration
Functional products need to be validated before marketing and these processes are expensive and time consuming	Invest in product testing, validation and clinical trials. Seek public and private investments
Many unforeseen problems arise during scale-up	Collaborate with experienced professionals, utilize reliable technologies and build on previous industrial experiences
Important to seek the available support and assistance	Utilize available support organizations and innovation centers
Scale-up, process demonstration and commercialization is high risk and difficult to fund	Seek governmental support through investments and/or incentives, as well as private investments

3.1.1 Recommended Actions

This section prioritizes the identified key actions needed to further support and advance the Nordic biorefining industry. The actions are based on analysis of stakeholder interviews and on the industries lessons learned and shared best practices, and outline the industries major requirements for improvements and support.

Action 1. Improving governmental framework and support
The Nordic biorefining industry needs clearer policies and a transparent and stable regulatory environment. This applies both within the region as well as in Europe. The biorefining industry needs similar initial governmental assistance, funding and incentives as previously emerging green technologies have had. Governmental support should focus on:

- Increased funding of research in biorefinery applications and biotechnology solutions to strengthen the industries basis and to advance product development for biorefinery profitability.
- Stable subsidization of innovative biorefining applications, mainly low value bioenergy products, during initial commercialization and product range development.
- Creating markets for biorefining products, particularly through increased blending mandates for transport fuels and public procurement.
- Supporting biorefineries through various tax incentives and by publicly promoting the concept of the Nordic bioeconomy.
- Investments in biorefining demonstration facilities and commercialization of promising innovative, but high risk biorefining applications (actions 2 and 3).

Governmental support and incentives will be a dominant force in encouraging private investments in Nordic biorefining.

Action 2. Bridging the gap to demonstration
The technical and financial risks of Nordic biorefining industries associated with scale-up and demonstration of innovative technologies need to be reduced through public investments. Several biorefining demonstration sites need to be built within the region and should be flexible to suit different applications, but also need to be designed for specific processing techniques and bioresources. The facilities should be governmentally run and available to the industry at low rental fees.

Action 3. Governmental co-investments for commercialization of innovative biorefineries
Increased public investments in the commercialization of innovative and developed biorefining applications is required to stimulate private investments, through reducing the risk of the industry and attract private investors. Further commercialization of different biorefining applications will give the industry needed market experience and the oppor-

tunity to demonstrate the potential of the biorefining sector. Political prioritization and focus on the initial commercialization of selected biorefining applications and products is recommended, in consultation with biorefining stakeholders. The prioritization should not be biased towards production of bioenergy products.

Action 4. Setting up a strong Nordic biorefining innovation center
There is a clear need for a strong and active co-Nordic biorefining innovation center providing a range of support to the industry. The support should be focused at:

- Expert assistance on commercialization, marketing, product registration, protection of intellectual property rights and the global regulatory environment.
- Providing regional overview of existing applications, product developments, test facilities, and collaboration- and funding opportunities.
- Feasibility mapping of biorefining products and market needs.

The above actions are also listed as Recommendation 11–14 under Excecutive Summary in the beginning of this report.

3.2 Business needs and opportunities/Consultancy reporting

3.2.1 Introduction

Governments within the Nordic region have given clean technologies and green growth high priority. As a part of this priority, the Nordic Prime Ministers have set up a green growth initiative for further development and progress of green industries and the green economy within the region (The Nordic Council of Ministers, 2015). Incorporating industry stakeholders and the industries perspective in these processes is of great significance for the success of the initiative.

The Nordic region is globally a small region and the Nordic countries need to increasingly focus on working together to succeed in mowing towards a sustainable bioeconomy and clean technologies, including biorefining. Biorefining is the process of refining various biomass feedstock for production of bioenergy and other bioproducts and industrial biorefineries have been identified as Europe's most promising route to a bio-based industry.

Many biorefinery initiatives have been launched within the Nordic region and are at all stages of development, working on a range of different types of biomass, refining processes and product development. Biorefinery products include renewable energy, which can replace oil-based products. The Nordic region has set high ambitions for reducing greenhouse gas emissions. Biofuels, together with other renewable forms of energy, will play a large role in achieving the EUs 2020 climate target of 20 % renewable energy, and at least 10 % renewable transport fuels (European Renewable Energy Council, 2007). Other types of biorefining products, bioproducts, include biochemicals and biomaterials such as polymers, composites, food, feed and health and pharma products. These products have great application and value potentials that have not yet been fully envisioned.

Biorefineries can be based on a range of feedstocks but biomass renewability is of high importance. Currently the major focus is on various non-food crops, by-products, waste products and under-utilized resources. The biomass is processed and refined for a particular product or products, such as proteins, amino acids, carbohydrates, sugars, fibres and lipids. The biorefining processes may include biomass fractionation for direct removal of products or further processing, biochemical breakdown and/or fermentation of biomass constituents to biofuels and bioproducts. This process is often referred to as the sugar (carbohydrate) and constituent biorefinery platform. Another process, the thermochemical or syngas platform, transforms biomass into gas or pyrolysis oil through processes similar to petroleum refining. Flexible biorefineries utilizing a range of sustainable biomass and with integrated production of multiple bioproducts will be a key factor in the development of an economically sustainable biorefining industry (World Economic Forum, 2010).

This survey report maps and analyses the major opportunities and challenges in the Nordic biorefining industry and lists recommendations to be made for support of the industry. This analysis has been done through interviews of Nordic biorefinery stakeholders, both from the biorefining industry and from supporting organizations. The report also lists important learning lessons and shared best practices from the Nordic biorefining industry. This survey was a support action for the Test Centers for Green Energy Solutions – Biorefineries and Business Needs project, supported by the green growth initiative of the Nordic Council of Ministers. The authors hope that this report and the industrial perspectives that it highlights, from Nordic biorefining stakeholders, will be integrated into the governmental and industrial processes undertaken to move towards a thriving and sustainable Nordic bioeconomy.

3.3 Methodology

3.3.1 Terminology

The term *biorefining* includes a range of different technologies, applications, and products and is not easily defined. The study adopted the broad definition of the IEA Bioenergy Task 42; *Biorefining is the sustainable processing of biomass into a spectrum of marketable products and energy.*

This report further divides biorefineries into two sectors, *bioenergy* and *bioproduct* biorefineries, based mainly on distinctive differences in their product range, but also on other factors, such as the specified opportunities and needs. Bioenergy biorefineries focus on producing energy products, such as biofuels and biogas, whereas bioproduct biorefineries, sometimes called biochemical biorefineries, focus their production on a range of bio-based products, other than energy products.

3.3.2 Stakeholders and Survey Participation

To analyse the Nordic biorefining industry major opportunities and needs, selected stakeholders were invited to participate in an interview survey. Stakeholders invited to participate included a range of bioenergy and bioproduct biorefineries operating within the Nordic region, as well as several supporting stakeholders. Supporting stakeholders included relevant authorities, public and private organizations, public and private research institutions, academia, and industries directly supporting Nordic biorefineries through technology- and process development and consulting, within the Nordic region.

The participants in the NCM funded project "Test Centers for Green Energy Solutions – Biorefineries and Business Needs" provided the survey conductors with a list of selected stakeholders to be contacted. The list contained 64 stakeholders from Sweden, Norway, Denmark, Finland, Iceland, Greenland and the Faroe Islands. To increase the number of participants, further 52 stakeholders were later selected by the survey conductors and invited to participate in the study.

Stakeholders were sent and invitation email where the company or organization was asked to participate in the interview survey. Subsequently, non-responsive stakeholders were sent a follow-up email and some were also contacted by phone. Stakeholders belonging to countries or sectors underrepresented in the survey were more extensively contacted for participation.

Stakeholders interested in participating in the survey were asked to sign up for an interview session through a booking website; https://nordicbiorefineries.youcanbook.me/, and subsequently contacted at the prearranged time for interviewing.

3.3.3 Interviews and Questionaire

Out of the 116 contacted stakeholders, 37 responded positively to the invitation and participated in the survey (see tables 35 and 36). Stakeholder interviews were performed over the phone, through Skype or face-to face and took from 20–40 minutes each. A questionnaire (Appendix) was designed to use as an interview guide during the interviews. The first half of the interview focused on biorefinery business analysis and the second half focused on identifying the industries major opportunities, needs and requirements and was divided into subsections based on different topics. All 37 interviews were conducted by the same person. The stakeholders' answers were noted by the conductor by filling in the questionnaire for each participant.

Table 35: Invited and participating stakeholders

Country	SE	DK	FI	NO	IS	GR	FO	Total
Number of invited stakeholders	22	20	21	33	13	4	3	116
Number of participants (%)	6 (27)	8 (40)	7 (33)	5 (15)	7 (54)	2 (50)	2 (67)	37 (32)

Table 36: List of participating stakeholders by country

Country	Companies
Sweden	Domsjö Indienz Lantmännen Agroetanol SP Energy Technology Center SP Processum SP Örnsköldsvik Demo Plast
Denmark	Arla BioGasol Bioefining Allinace CLEAN DONG Energy Hamlet protein KMC Novozymes

Country	Companies
Finland	Arizona Chemical Finnoflag Kekkila Neste Jacobs Pöyry St1 Biofuels UPM-Kymmene
Norway	Borregaard Innovation Norway NMBU PFI Treklyngen
Island	Algalif Genis Iceprotein Marinox Orf Genetics Prokazyme SagaMedica
Greenland	Greenland Institute of Natural Resources Royal Greenland
Faroe Islands	Fiskaaling Research Park iNOVA

Responses from stakeholders were used as a basis for data analysis. Data was transformed into tables and figures and statistically analysed. Z-test was applied to compare bioenergy and bioproduct stakeholders answers and the significance level was set at 0.05. Participants responses were analysed based on the focus and prioritization of the particular subjects given in the interviews, as well as the number of occurrences. The data was analysed as a whole, but was also divided based on whether the stakeholders were identified as bioenergy-related or bioproduct-related. Bioenergy-related stakeholders included biorefineries focusing on the production of bioenergy products, such as biofuels, biogas, heat and power, as well as stakeholders mainly supporting bioenergy biorefineries and/or focusing their answers on matters related to bioenergy biorefineries. Similarly, bioproduct-related stakeholders included biorefineries focusing on the production of bioproducts, such as food, feed, chemicals and materials, and supporting organizations and industries mainly supporting bioproduct biorefineries and/or focusing their answers on matters related to bioproduct biorefineries. The number of participants was too low to effectively analyse differences between countries, although it is believed to give a good overview over the Nordic region as a whole.

3.4 Survey Results and Analysis

This report on the major opportunities and needs of the Nordic biorefining industry is based entirely on the views of 37 Nordic biorefinery stakeholders from Sweden, Norway, Finland, Denmark, Iceland, Greenland and the Faroe Islands. Twenty stakeholders from the biorefining industry, along with 17 biorefining support organizations, participated in the survey through interviews.

3.4.1 The Nordic Biorefining Industry

The major opportunities and needs of Nordic biorefineries, according to the survey, are reported in this section. The section also includes background information and basic business analysis of the participants. The emphases of all the participating stakeholders are formulated by categories. In some areas the opportunities and needs differed between stakeholders focusing on bioenergy production and those focusing more on bioproducts. Those differences are reported in subsequent chapters; 3.4.2. *Focus on Bioenergy* and 3.4.3. *Focus on Bioproducts*.

Bioenergy

Bioenergy is energy derived from the conversion of biomass, where biomass may be used directly as fuel, or processed into liquids and gases.

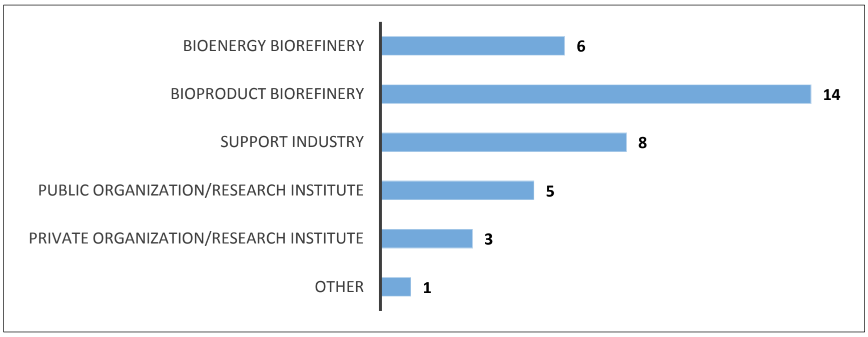
Bioproducts

Bioproducts are a range of chemicals and materials, other than energy, derived from biomass refining or conversion.

Participating Stakeholders

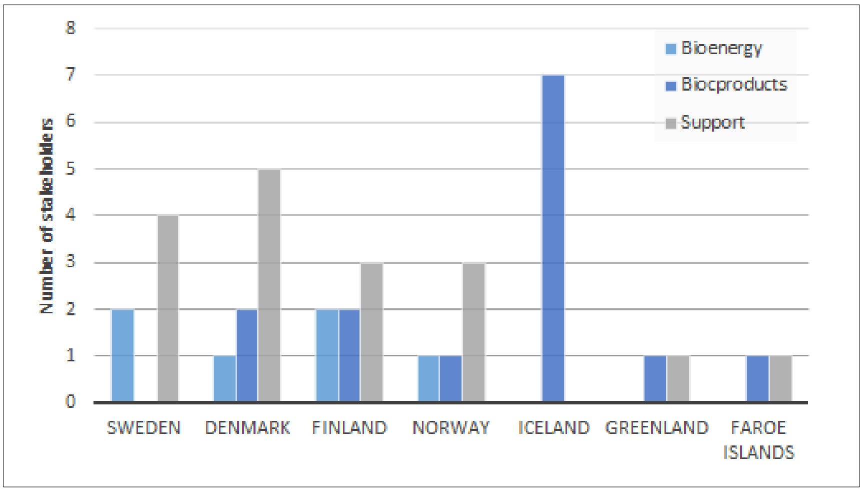
The 37 participating stakeholders represented a diverse range of biorefineries, industries directly involved in supporting biorefineries and various research institutions and organizations involved in biorefining. The biorefineries were divided into bioenergy and bioproduct biorefineries, based on the focus of their production and answers given during the interviews. The number of participants in each category is shown in Figure 5. Twenty biorefineries participated in the survey. Four out of the six bioenergy biorefineries produced bioproducts as side streams, while only one out of the fourteen bioproduct biorefineries produced bioenergy as a side stream. Eight supporting industries participated in the survey, providing biorefineries with equipment, processing technologies, testing facilities and consulting. One stakeholder, a large-scale consumer of bioenergy, was categorized as "other". Hereafter, the 17 participating stakeholders that are not industrial biorefineries will be referred to as *support organizations* or *support stakeholders*.

Figure 5: Types of participating stakeholders. Exact numbers of participants are indicated next to each bar



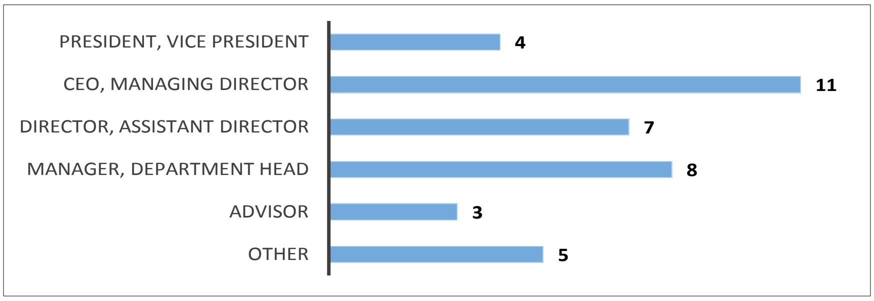
Denmark, Finland and Norway had 8, 7, and 5 participating stakeholders, respectively, representing the three sectors of bioenergy, bioproducts and support organizations. (Figure 6). Sweden had 6 participating representatives from the bioenergy and support sectors. Iceland had 7 representative stakeholders, all from the bioproduct sector, while Greenland and the Faroe Islands each had 2 representatives, from the bioproduct and support sectors.

Figure 6: Division of participating stakeholders by type and country



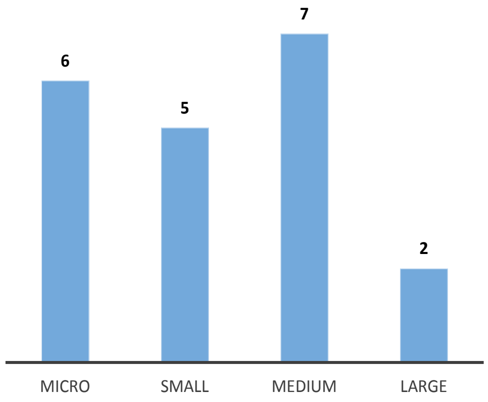
The interwieved contact persons provided a general good overview of all the different sectors included in the survey, such as processing techniques, products, markets and the regulatory framework, and many of them were in administrative positions (Figure 7). One contact person provided information on behalf of each stakeholder organization, except for one organization where two contact persons participated in the interview.

Figure 7: Position of stakeholder contact persons. Exact numbers of contact persons by category are indicated with next to each bar



The size of the 20 participating industrial biorefineries was defined based on the number of employees involved in the biorefining operations within the company as shown in Box 1. For globally operating companies the number of employees within the Nordic region was used. There was a good distribution of stakeholders in the range of micro, small and medium sized biorefineries, and two biorefineries were classified as large (Figure 8). No participating biorefinery had more than 1,000 employees. Representatives of both bioenergy and bioproduct biorefineries of all four size categories were included in the survey.

Figure 8: Size of participating Nordic biorefineries



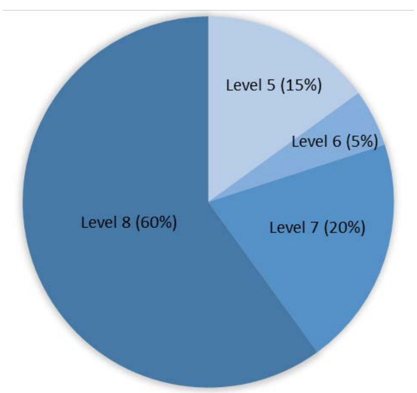
Box 1 Size of biorefineries by number

Micro ≤ 10
Small 11-50
Medium 51-250
Large 251-1000

Note: Exact numbers of biorefineries by category are indicated above each column.

The readiness level of the 20 biorefineries was categorized as shown in Box 2. Several biorefineries were at various readiness levels as they are developing a range of products at variable levels of maturity. These biorefineries were assigned a level based on their main product or their most advanced product. None of the participating biorefineries were at the first levels, ranging from basic principle to preliminary technical evaluation, while most were already at established sustainable production (Figure 9).

Figure 9: Readiness level of participating Nordic biorefineries



Box 2 Readiness level of biorefineries

1 - Basic principle/concept
2 - Formulated concept
3 - Proof of concept
4 - Preliminary technical evaluation
5 - Process validation/pilot scale testing
6 - Full-scale production evaluation
7 - Commercialization
8 – Established sustainable production

Biorefineries at readiness levels 7 and 8, commercialization and established sustainable production, were asked how long it had taken the company to get from level 1, basic principle, to the current level. Many of the participants found the question difficult to answer but the average time mentioned was just over 13 years, ranging from 4 to 20. However, it was noted that development of new products in an already established biorefinery was achieved much faster, with development processes ranging between 2 and 6 years.

Limitations of the Study

The main limitation to this analysis is the relatively low number of participating stakeholders. Only 37 out of the 116 (32%) contacted stakeholders participated in the survey. The number of participants is too low to reliably identify any possible differences between the Nordic countries, although the study is believed to give a generally good overview of the region as a whole. National differences, such as in types of available biomass, size of biorefineries, product range, or variable governmental support could therefore not be analysed. Furthermore, the number and type of stakeholders does not correctly reflect the prevalence and scope of biorefining operations within each country or within the region. This should be considered for the analysis and interpretation of the survey results. Nonetheless, the interviews revealed some very clear and frequently occurring trends common to most stakeholders representing different sectors, countries and biorefining applications.

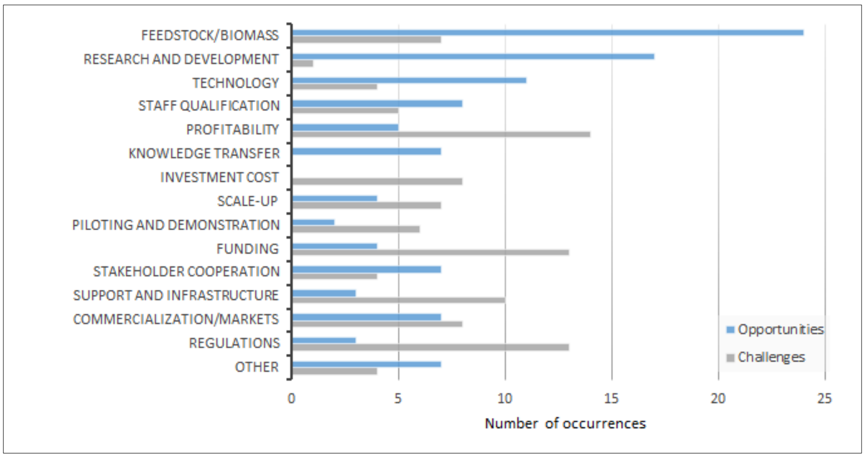
Major Opportunities and Challenges

Stakeholders were asked to identify the major opportunities and challenges for Nordic biorefineries. Each participant was allowed to select up to four categories out of a list of categories presented to them. The results are shown in Figure 10. The participants identified the regions feedstock availability, sustainability and potential as a major opportunity, followed by the level and status of research and development (R&D) and technology. Ongoing strong and generally good cooperation with various universities and research organizations, especially on the level of basic science, was mentioned as an important support to the biorefining industry. Major opportunities mentioned which did not fall within the given categories and shown as "other" in Figure 10 included increased energy independence and waste recycling, reduction in greenhouse gas emissions and increased employment within the region.

The main identified challenges were profitability, funding opportunities and the regulatory framework, but were otherwise rather evenly distributed between the different categories (Figure 10). The lack of profitability for bioenergy products was an important concern, whereas the potential profitability of bioproducts was identified as a major opportunity by five stakeholders. The partially supportive and clear regulatory framework was mentioned as an opportunity by three Finnish biorefineries. High cost of labour within the Nordic region was mentioned as a major challenge.

The subsequent sections will cover the different categories listed in Figure 10 and report the major opportunities, challenges and suggestions for improvement and action based on the stakeholder interviews.

Figure 10: Major opportunities and challenges of the Nordic biorefining industry

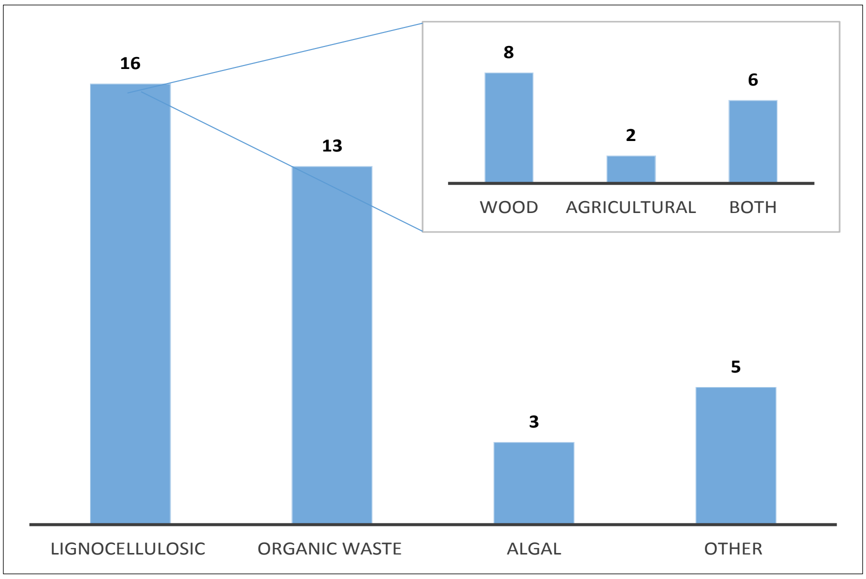


Biomass

The Nordic region has high quantities of sustainable biomass of great potential value for use in biorefining. Biomass was identified as the region's major opportunity. There was a clear emphasis on utilization of sustainable biomass and its role as an underlying basis for the Nordic biorefining industry.

The types of available biomass are quite variable within the region. Stakeholders from Finland, Sweden and Norway focused mostly on wood-derived biomass, which utilization can be supported by established value chains, technologies and equipment from the existing forestry, pulp/paper and chemical industries. In a recent report, Skog22, national strategy for the Norwegian forestry and wood industries is presented and the potential of bioenergy and bioproducts from wood is described (Strategigruppen SKOG22, 2015). Stakeholders from Denmark focused on straw utilization, an agricultural side stream, and household and industrial waste. Iceland, Faroe Islands and Greenland focused mostly on utilization of sustainable natural biomasses and waste from fish and shellfish processing industries and household waste. The specific opportunities for the future bioeconomy of the West Nordic countries have recently been reported (Smaradottir *et al*., 2014). The types of biomass utilized by the participating biorefineries, and focused on and researched by the supporting stakeholders, are shown in Figure 3.7. Most of the participating stakeholders were currently working on the utilization of one type of biomass, lignocellulosic, waste, algal or other. Several biorefineries, however, worked on different types of biomass within each category. Lignocellulosic biomass was further divided into wood or agricultural biomass (inset figure 11). The importance of a flexible biorefinery, capable of utilizing a range of biomasses was commonly mentioned as a key element in biorefining applications and for profitability, parallel to developing a range of valuable products. Increased biorefinery flexibility therefore seems to be a task for the future.

Figure 11: Types of biomass utilized and/or researched by participating stakeholders



Note: The inset figure shows further division of lignocellulosic biomass. Exact numbers of stakeholders working with biomass of each category are indicated above each column.

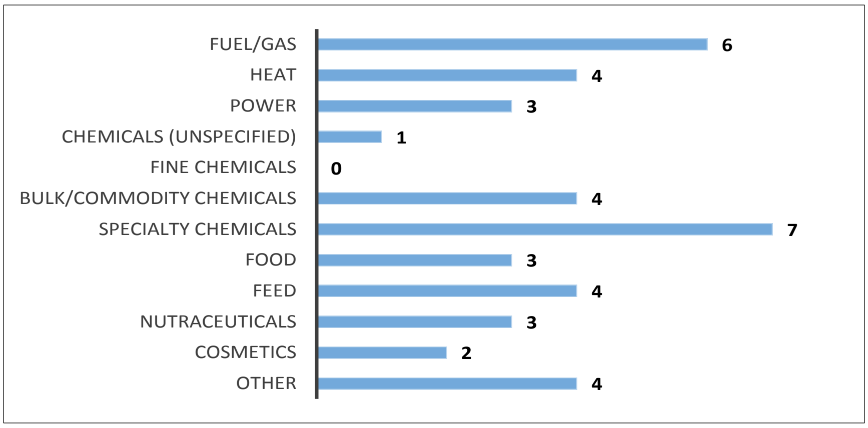
Stakeholders emphasized that there should not be too high demand on initial degree of biomass utilization and that this may not be a hindering factor for novel process development. They stated that the focus now should be on biorefinery scale-up and that the degree of utilization will later improve through experience, R&D and increased product range. High cost of biomass, mainly wood, was mentioned as a challenge to biorefineries, especially the feasibility of bioenergy products. Governmental subsidization can, however, compensate for the high cost of biomass.

Clearer and stricter regulations and increased governmental incentives on organic waste recycling and utilization could strengthen waste-based biorefining industry. Improvements regarding infrastructure and logistic are also valuable for increasing biorefining feasibility and profitability.

Products and Markets

The range of products produced by the 20 participating biorefineries is shown in Figure 12. The range of products produced among the participants was quite diverse, with specialty chemicals and fuel and gas being the most common products. The average number of product categories produced by bioenergy biorefineries was 2.7, and 1.7 for bioproduct biorefineries. Four out of six bioenergy biorefineries produced both bioenergy and bioproducts, while only one out of 14 bioproduct biorefineries produced bioenergy as a side-product.

Figure 12: Types of products produced by participating biorefineries



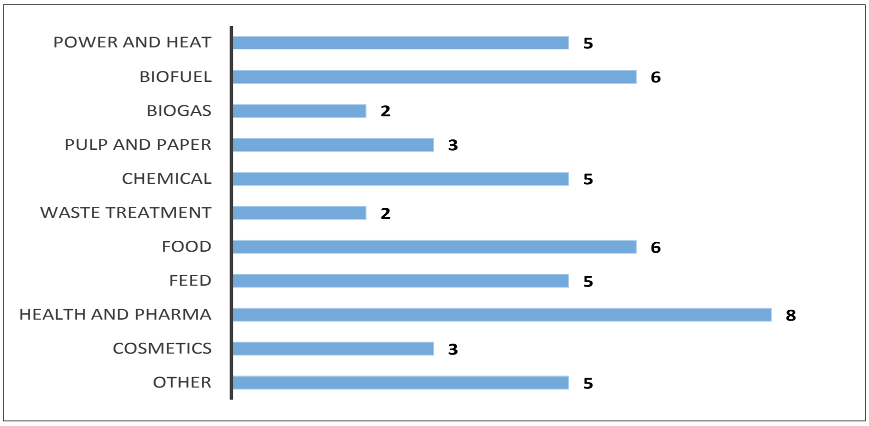
Note: Exact numbers of biorefineries producing each product type are indicated next to each bar.

Stakeholders clearly identified multi-stream biorefineries, producing a range of products of different value, as a key factor in biorefining sustainability. However, they stated that it is now time to launch developed bioenergy applications, which are believed to be ready for market in order to establish the industry; despite possible product low value and no/low profitability (see further section Scale-up and Commercialization). Stakeholders called for better overview over the biorefining product spectra and insight into which products are currently being developed on an industrial basis.

There were some concerns over growing general opposition of the use of genetically modified organisms (GMOs) within the Nordic region and across Europe. There was a common agreement among those who discussed this topic that the problem will be difficult to tackle. One way could be to have authorities and the scientific community actively convey information to the public on the potentials and value bio-based products, including those produced by the use of GMOs. The need for and value of GMO applications could also be emphasized. Nordic governments should also increasingly try to influence EU scientific committees on matters of GMO use in biorefining.

The types of markets to which the products produced by the participating biorefineries are sold to are listed in Figure 13. The rather evenly distributed and wide range of market types reflects the range of biorefining products produced. The health- and pharma markets were the most commonly mentioned markets, followed closely by biofuel-, food- and several other market types. The diversity of markets is also a challenge for biorefineries as many will need to have marketing expertise that cover a range of market types.

Figure 13: Biorefinery product markets



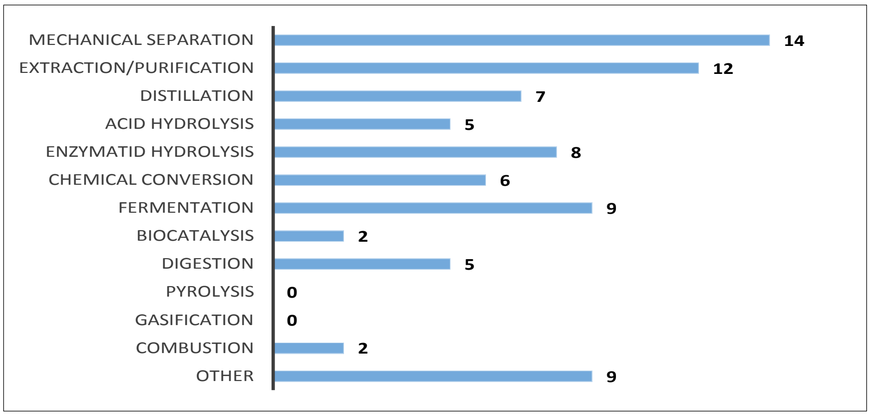
Note: Exact numbers of biorefineries producing products for each market category are indicated next to each bar.

One of the central themes in the survey is the importance of marketing biorefinery products. The marketing aspect is a very demanding and crucial phase in the development of biorefining industries and many of the biorefining entrepreneurs lack the necessary professional marketing skills. Professional marketing support and overview of market research, needs, and demands should be readily available and should be offered increasingly to small start-up biorefining companies at national or regional innovation centers (see section Support Centers, Test-, Pilot-, and Demonstration Sites). A comprehensive study of bioenergy and bioproduct market needs and product value is also required. Furthermore, start-up companies can be assisted by giving financial support to attend sales meetings and conventions to promote and market their products.

Technology and Processing Techniques

Participating biorefineries and support organizations working on specific processes were asked to identify the types of processing techniques used. The stakeholders apply a range of techniques in their processes, listed in Figure 14, with mechanical separation and extraction/purification being the most commonly used methods. None of the stakeholders identified pyrolysis or gasification as a processing technique used. The participating stakeholders representing the Nordic biorefining industry are therefore focusing primarily on the sugar- or biochemical platform, rather that the thermochemical platform. Techniques categorized in Figure 14 as "other" mostly included evaporation and drying. Increased focus and research on enzymatic treatment and conversion of biomass, currently a challenge, was mentioned as an important aspect for further process and product development.

Figure 14: Types of processing techniques used by stakeholders



Note: Exact numbers of stakeholders applying each type of processing technique are indicated next to each bar.

Technology was identified as a significant enabler of the biorefining industry and there are huge opportunities in the development of new technologies and equipment. However, much of the necessary technology is already available and only needs to be adapted to new or more flexible applications. Utilizing supporting background and knowledge transfer from other industries, including the pulp and paper industry, is very important. There were some concerns regarding small start-up companies providing novel technologies and equipment and the reliability of the equipment in large-scale production and the risk that brings to the biorefineries. There may be some lack of skills within the biorefining industry in scale-up and it will be necessary to bring the right players to the task, with relevant background in process and technology development and scale-up.

Intellectual Property Rights

Several biorefining companies stated the importance to retain intellectual property rights (IPR) of innovative processes and technologies. Smaller companies often avoid patenting due to the high cost and complexity of the process. Views on whether they should or should not get public financial support for patent applications were different. However, start-up biorefining companies should be encouraged to patent their processes and products, and offered some professional assistance. There were some conflicting interests between biorefineries and supporting research organizations regarding who should retain IPR following cooperation between the sectors. Biorefining companies stated that they should own, or at least share, IPR following such collaborations.

Research Development and Funding

Biorefineries generally stated that they receive good support from the research sector. Increased efforts should be put into innovation and basic research in the field of advanced and higher value bioproducts from sustainable biomass. This research area will be very important to the profitability of the biorefining industry. Identification and research of conversion techniques yielding high value products should also receive more attention, including research on enzymatic treatments and conversions and processing organisms.

Biorefinery stakeholders in the Nordic region have access to various research and developmental grants to fund basic and initial application research. The Nordic countries have focused much of their public funding on basic R&D and proof-of-concept, ant that has been crucial for the initial development of the biorefining industry. Almost all participating stakeholders had received national, Nordic and/or European funding for research and development. Funding for basic research should be increased and sometimes extended over time for supporting more ambitious projects aiming at commercial applications. Authorities should identify and prioritise some initial key processes and applications which then would receive increased support for further development. Selected promising projects should increasingly be supported for demonstration. In general, biorefining research projects were seen as relatively easy to initiate, but it is difficult to continue and actualize promising processes. Increased funding to technology developers/suppliers, as well as to research organizations and biorefineries, could benefit more stakeholders. Authorities are encouraged to identify and prioritize some main biorefining processes and applications and then focus on helping them to emerge. The region is now at a point where large public and private investments and public funding for financing demonstration and scale-up to commercialization are needed (see section Scale-up and Commercialization and section Support Centers, Test-, Pilot-, and Demonstration Sites). The Horizon 2020 research and innovation programme gives good support for innovative testing, scale-up and demonstrations, but governmental and private funding is needed and high requirements of co-funding are difficult to meet.

Support Centers, Test-, Pilot-, and Demonstration Sites

There is a clear need for a strong Nordic biorefining innovation center, where biorefinery stakeholders can seek cooperation, get information on the different aspects of the biorefining industry, including funding, research, regulation and marketing, and which provides overview of the existing operations both within the Nordic region and in Europe. Increased support and overview of the regulatory framework of the Nordic region and at the European level will be very important, and European legislations and directives will have a large impact on the market for biofuels and bioproducts in the region. Furthermore, there should be clear and transparent guidelines for businesses to follow for each type or group of products/compounds being led to market and expert help needs to be readily available regarding the regulatory framework and registration to markets.

The need for application facilities varies different between the Nordic countries, sectors and by scale. Overall there is a demanding need for large-scale demonstration sites for the scale-up of different applications, as well as to strengthen existing facilities. This is one of the surveys major findings. Facilities should be flexible to suit as many applications as possible. Some stakeholder mentioned that they feared that their applications may be too specific for existing demonstration facilities and others were not very familiar with which kind of facilities were available to them. Therefore, there is a need to provide the industry with good overview of the existing available facilities, an action which has been initiated and is taking place both at Nordic and national levels. Better utilization and co-utilization of existing facilities and equipment could be achieved and should be encouraged. National collaborations focusing on pilot facilities should increasingly work together within the Nordic region to strengthen the Nordic biorefining industry, including the more rural areas. Stakeholders stated that test facilities of different sizes should preferably be governmentally run through public research institutes and rented out with increased support from governments at a low cost to companies developing innovative processes and products. Seven of the participating stakeholders provided test- pilot- or demonstration facilities available for the biorefining industry. The facilities were of different sizes and focused on various applications and processes.

Scale-up and Commercialization

One of the most significant trends from the survey is the urgent need for increased efforts in scale-up to pilot-scale or demonstration for start-up biorefineries, as well as the commercialization of biorefineries that have successfully completed the demonstration phase. These mostly include bioenergy biorefineries. Several biorefining companies have developed the necessary processes and have products ready for demonstration scale or commercialization. This situation can be seen as a huge opportunity for the region but it needs to be utilized.

There is a great need for helping start-up biorefining companies through the "Valley of Death", a term used to describe the lack of financing and the financial risk from start-up to commercialization. Research and development grants fund the basic and initial application research but then most companies face a gap in financing, the Valley of Death, from early proof-of-concept, through demonstration and scale-up for commercialization. These steps are mostly funded by governmental support, venture capital and private equity. There is a huge requirement for increased funding of these steps and political participation and encouragement is needed to attract private capital. Currently, too many promising start-up companies give up at the early stages because of these difficulties and the funding provided for the initial development is therefore not optimally utilized.

There may be a need to set a specific initial political prioritization on the demonstration and commercialization of selected applications and this should be more clearly formed by the authorities. The production of bioethanol as a bulk product is one of the applications which could receive initial focus for proof-of-concept as the processes and technologies are relatively advanced. The region needs to adapt a more aggressive "all-in" attitude towards proof-of-concept in biorefining, from all sectors, including start-up companies, entrepreneurs and authorities. This all-in attitude will most likely positively influence the participation of private investors. However, the focus on higher value bioproducts should not be forgotten, but emphasized and integrated, into the processes of demonstration and commercialization.

The biorefining industry in the Nordic region needs to have several full-scale biorefineries operating for proof-of-concept. This will subsequently give way to more products, preferably of higher value and lead to the sustainability of the process. Once the success has been demonstrated, the industry and private investors will follow. It is important to act soon as there is confidence in that the region has a competitive strength in this filed. That strength should not be lost or wasted and the region needs to be progressive not to lose its competitive edge. The step from demonstration to commercialization needs to be taken now and needs to be significantly funded by public financing and/or governmental loan guarantees. There should also be strong governmental investment in demonstration facilities within the region.

Governmental Framework and Support

The primary need of the Nordic biorefining industry is the need to improve the governmental framework, both within the Nordic region and across Europe. The biorefining industry calls for clearer policies and long-term regulatory stability. As the regulatory framework of the EU affects the Nordic biorefining industry substantially, the Nordic countries should increasingly collaborate to influence Europe's regulatory framework, including EUs 2030 policies of climate and energy and continued cooperation within the European Industrial Bioenergy Initiative (EIBI).

Previously emerged sustainable green technologies or cleantech, such as renewable energy, recycling and sewage treatment have generally had good political support and favourable legislation within the Nordic region. This has given the region a certain frontrunner position in many of these green technologies. The biorefining industry needs similar initial governmental assistance, funding and incentives as previous green technologies have had. The Nordic governments show the emerging bioeconomy, including biorefining, considerable support and interest and generally have good focus on renewability, reduction of greenhouse gas emissions and increased energy independency. There is also good political focus on sustainable biomass utilization and bioenergy. This political interest and backup is encouraging to the Nordic biorefining industry and private investors. However, there is an apparent lack of clear long-term political initiatives, incentives and regulatory framework for the industry. Furthermore, there is a certain degree of urgency to improve this as many biorefineries are at the starting phase of scale-up and commercialization, which demands significant investments. Governmental incentives will be an important drive to encourage investors to risk investing in bioenergy and bioproducts. This problem should be addressed immediately and given high priority.

The legal and regulatory framework is extremely relevant for the biorefining industry. The bioenergy industry is especially dependent on the political climate since it cannot as a stand-alone product compete with fossil fuels on an economic basis. However, it should be emphasised that the regulatory environment within the region was also mentioned by several stakeholders to be partially supportive and transparent, compared to other countries. Environmental and safety regulations were also mentioned to be appropriate and at good levels of accountability.

Three political focus points to support the development of the Nordic biorefining industry and to attract investments within in the sector:

Firstly, the primary drive, objective, and target of the Nordic biorefining industry should be clearly formed by governmental bodies. Several stakeholders stated that it is unclear where the focus lies. Is the focus on profitability, social issues and employment, or environmental factors? If the focus is on profitability, then bioproducts should be made a priority as bioenergy is not profitable on its own. The biorefining industry calls for a clearer focus and prioritization by governments. The industry needs political lead and guidance on how best to replace fossil fuels and where the primary focus should be. There needs to be a transparent overview over the main focuses and possibilities. The involvement of the biorefining industries in advising governmental bodies on the regulatory framework, governmental support, and prioritization of applications and products, needs to be carefully integrated into the process.

Secondly, the political framework needs to be clearer and more transparent and give the biorefining industry long-term regulatory stability of 5–10 years. Currently, short-term regulations and policies are believed to be a major inhibition to investments in the sector. Stakeholders find the regulatory framework hard to monitor, follow and understand. The regulatory framework should optimally be cross national and worked on in close cooperation with other regions committed to biorefining.

Thirdly, the biorefining industry needs increased political incentives due to the lack of product profitability, at least in the first years of production. This may particularly apply to bioenergy products which are not as stand-alone products profitable. Political incentives are a key factor in encouraging and enabling private investments.

Specific governmental incentives

Governmental investments: The biorefining industry needs long-term capital for product development, scale-up and commercialization. Many biorefineries will need 10–15 years to develop economically sustainable production from start-up. Strong Nordic and European investment funds and funding for establishment of large-scale production facilities are needed. There was high emphasis on the current need for investments in demonstration and full-scale production facilities. The investment in scale-up is high risk and the companies and investors risks need to be reduced by governmental involvement. Stakeholders mentioned that governmental involvement in scale-up should ideally be between 20–60% and should depend on the potential innovative impact. Governmental investment priorities should be clear and not biased towards bioenergy and should focus on a range of promising innovative applications and value cascading applications.

Subsidies: Governmental subsidization of bioenergy, and to some extent bioproducts, needs much more long-term stability to encourage larger investments. The industry needs a minimum of a 5–10 year perspective. Not having a clear view over the support system is greatly hindering the industries growth and is unsupportive to investments. Investors need to make long-term investments and commitments and therefore need long-term regulatory framework stability. New bioenergy biorefining companies will particularly need governmental subsidization, at least until the development of higher value co-products is achieved together with better utilization of the biomass. The industry should preferably not be subsidised for the long term.

Blending mandates: There is a need to create good markets for biofuels and the best way will be to have clear volumetric biofuel blending mandates for transport fuels of 5–10%. The governments should adopt a more aggressive approach to blending mandates than they currently do, for example with legislation of mandatory blending of biofuels. The larger the market region the better, so preferably there should be focus at implementing this at the EU level.

Tax incentives: Tax reliefs and tax exemptions are valuable governmental tools which can support the Nordic biorefining industry. R&D tax incentives in the form of tax deductions or refunds were specifically mentioned as a very important form of support by several start-up companies. Public procurement or preferences of bioenergy and bioproducts may also be a good way to promote the Nordic biorefining market. Tax incentives for bioenergy products rather than bioproducts should not be raised and should not give preferences to the bioenergy industry.

The Nordic biorefining industry will need substantial initial governmental support. However, it was clear from the stakeholders' viewpoint that most of the governmental support needed will be temporary. The support should primarily be focused at innovative processes and products and the initial commercialization setups. Pioneers of the different biorefining technologies will need assistance and some security as they are leading development of innovative solutions to market. However, in the long-term the Nordic biorefining industry should develop and find economical sustainability through increased biomass utilization and development of novel valuable products. A recent review of the status of biorefining policies further describes these issues (Schieb & Philp, 2014).

Further support could be achieved through public outreach and involvement. Nordic authorities, public and private organizations, and the biorefining industry should increasingly promote the importance of the bioeconomy concept for the region. The public should actively be informed and educated on sustainability of biofuels and bioproducts and the importance of replacing fossil fuels. This may directly affect public preferences and increase demand for biorefining products. Subsequently, companies and service providers could see clear marketing benefits from either buying or selling such products. There may also be given additional political support through statements around the industry.

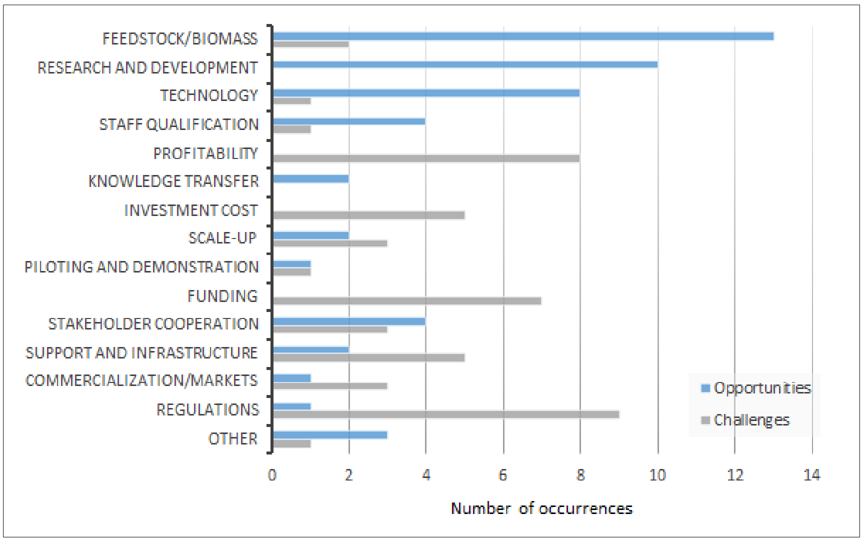
3.4.2 Focus on Bioenergy

The following sections report and highlight the distinctive features and responses of the participating Nordic bioenergy biorefineries and the supporting organizations. The survey included six bioenergy companies from Finland, Sweden, Denmark, and Norway, and supporting stakeholders from the same countries.

Major Opportunities and Challenges within the Bioenergy Sector

The bioenergy sector identified biomass, R&D, and existing technologies as major opportunities (Figure 15). A significantly higher ratio of stakeholders within the bioenergy sector identified technology as a major opportunity, compared to stakeholders in the bioproduct sector. Lack of product profitability, funding and the regulatory framework were identified as the main challenges within the region, although other categories were also often mentioned as major challenges (Figure 15). A significantly higher ratio of bioenergy-related stakeholders found the regulatory framework to be a principal challenge, compared to bioproduct-related stakeholders.

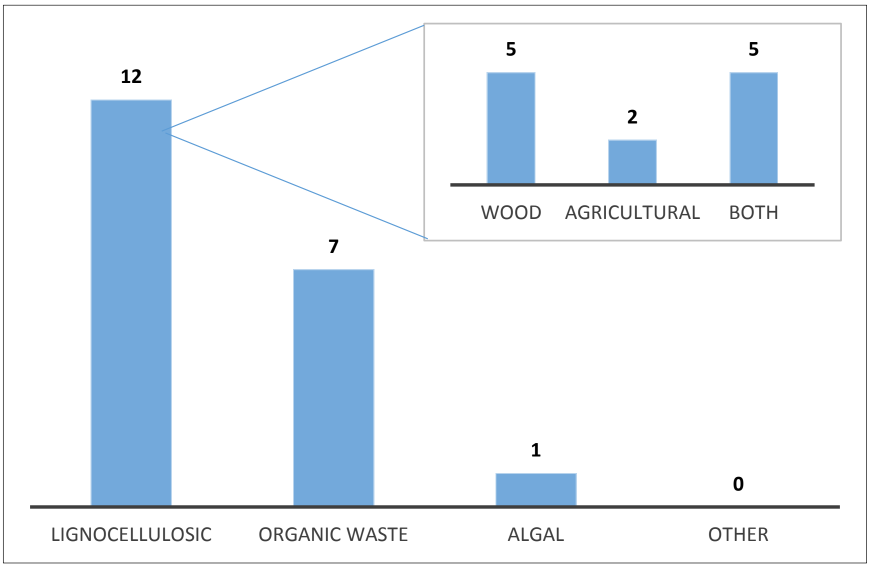
Figure 15: Major opportunities and challenges within the bioenergy sector



Biomass for Bioenergy

There was significant focus within the bioenergy sector on utilization of lignocellulosic biomass, but also on industrial and household waste (Figure 16). The lignocellulosic biomass was further divided into wood or agricultural biomass, which mostly included straw. Two bioenergy companies were utilizing grains, a typical 1st generation biomass. The grains were, however, categorized as waste as the grains utilized were of suboptimal quality for use in food and feed. One supporting stakeholder was working on developing algal biomass for bioenergy production.

Figure 16: Types of biomass utilized and/or researched by the bioenergy sector



Note: The inset figure shows further division of lignocellulosic biomass. Exact numbers of bioenergy stakeholders working with biomass of each category are indicated above each column.

Bioenergy Products and Markets

Four out of the six participating bioenergy producing companies produced chemicals and feed as side-products, while two produced only bioenergy. The bioenergy sector has developed a range of energy products, mostly biofuels, which have successfully completed piloting and demonstration phases and are ready for commercialization. The need for scale-up and demonstration of bioenergy products is pressing. The market for bioenergy products requires high value co-products or subsidies in order to compete with conventional energy products. The sector will depend on governmental subsidies, at least for the first years. With the current low prices of fossil fuels it is extremely difficult for bioenergy products to compete. The development of other bioproducts, which will yield increased biomass utilization and potentially have higher value, will take some additional time to develop but are hoped to make biorefineries economically sustainable and free of subsidies. The Nordic region should focus on building a platform of basic initial products to give the local biorefining industry a good start and then move the industry towards more variable and complex products. There are important possibilities in expanding the application range of bioenergy products which should be explored, as well as the potential to create new markets for biofuels, both within the Nordic region as well as globally.

Governmental Framework and Support for Bioenergy

The bioenergy industry is especially dependent on the political climate and support since it cannot, with the use of current technologies, compete as a stand-alone product with fossil fuels on an economic basis. Therefore, political incentives such as subsidies and mandatory blending are particularly important to support the sector and this was thoroughly discussed by the stakeholders. The most relevant bioenergy incentives; subsidies, blending mandates and governmental investments are listed and discussed in section "Governmental Framework and Support".

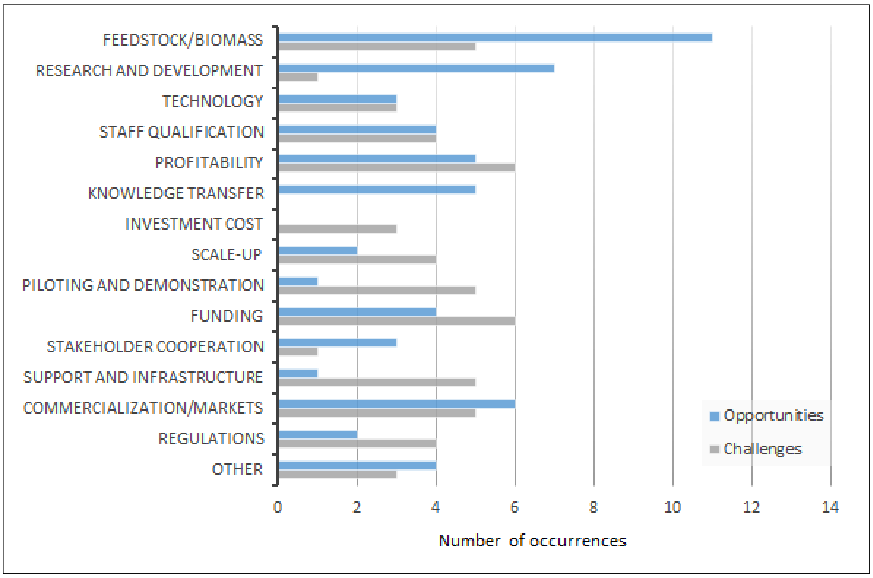
3.4.3 Focus on Bioproducts

The following sections highlight the distinctive features and responses of the 14 participating Nordic bioproduct biorefineries and the supporting organizations. The survey included bioproduct biorefineries from all the participating Nordic countries, except Sweden, and supporting organizations from all the countries, except Iceland.

Major Opportunities and Challenges within the Bioproduct Sector

The major identified opportunity within the bioproduct sector was the availability and potential of the existing renewable biomass (Figure 17). Several other categories were frequently mentioned as a major opportunity for the region, mainly R&D, and commercialization and markets. A significantly higher proportion of bioproduct-related stakeholders identified profitability as an important opportunity, compared to bioenergy-related stakeholders. No particular category stood out as a major challenge for the biorefining sector, but profitability and funding were the two most often mentioned categories. This was different from the rather clear pattern of regulatory framework and profitability challenges mentioned within the bioenergy sector.

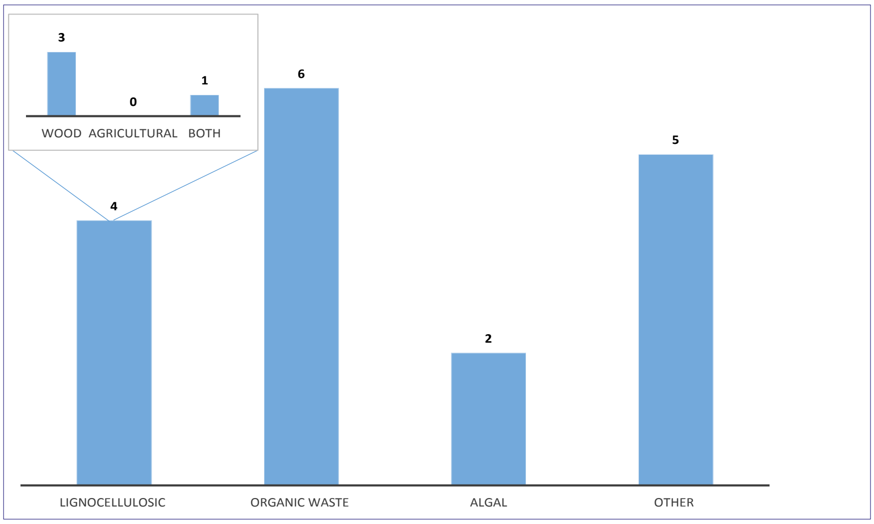
Figure 17: Major opportunities and challenges within the bioproduct sector



Biomass for Bioproducts

The bioproduct industry was working on a diverse range of biomass (Figure 18) and there was good focus on waste utilization. Two bioproducts companies were working with algal biomass for production of specialty chemicals, nutraceuticals and cosmetics. No bioproducts were produced from agricultural sidestreams.

Figure 18: Types of biomass utilized and/or researched by the bioproduct sector



Source: The inset figure shows further division of lignocellulosic biomass. Exact numbers of bioproduct stakeholders working with biomass of each category are indicated above each column.

Development of innovative processes and new revenue streams from biomass is very important to many industrial sectors in the Nordic region, perhaps particularly the wood-based forest industry, following the shut-down of several pulp and paper mills. Wood is not an inexpensive biomass and it is therefore especially important to focus on developing and producing valuable products from wood for economically sustainable production of wood-based biorefinery products. Forestry biomass is believed to be well suited for production of various valuable bioproducts, in addition to bioenergy. Macro- and microalgal harvesting and production are also very interesting for further refining into bioproducts, as well as bioenergy products.

Bioproducts and Markets

The bioproduct sector produced a wide range of products, but only one out of 14 bioproduct biorefineries produced bioenergy as side-products. Several stakeholders expressed the opinion that authorities have been directing he biorefining industry too much towards bioenergy instead of various bioproducts of higher value. The biorefining industry should be looked at as a multi-stream process from the beginning. Bioproduct stakeholders generally stated that bioenergy focused biorefineries ready for application should be commercialized at this time point, but that development of higher value co-products should also be given immediate attention. The need for mapping bioproduct feasibility and market needs was mentioned by several stakeholders for identifying the range and potential of the various possible products. Innovation and product development and upgrading is a major opportunity within the bioproduct sector.

Several of the participating bioproduct biorefineries are producing functional bioproducts, i.e. products with specific claimed functions such as functional food and feed, nutraceuticals, and pharmaceuticals. These products need to be tested and verified in various experiments and sometimes also in clinical trials before going to market, to ensure product safety, effectivity and marketability. Producers of these types of products need increased expert and financial support to get their products and claims verified, to go through clinical trials and to register products to markets, both domestically and globally. Access to expert consultancy on these matters is apparently lacking. Product or compound registration is often a complex and costly process and obtaining a novel or non-traditional product claim within the EU was specifically mentioned in regards to this and said to need more transparency. Governmental financial support to invest in claim verification and clinical trials is very important for companies developing these functional products.

To many, the image of the Nordic region is that of purity, clean environment, safety, technology and innovation. This can and should be an important aspect in the global marketing of Nordic biorefinery products, especially bioproducts, and was extensively utilized by some of the participating stakeholders.

Governmental Framework and Support for Bioproducts
The bioproduct sector first and foremost seems to need a strong funding body for commercialization, similar to the Norwegian energy fund, Enova, and marketing support. Furthermore, public support should not favour bioenergy products over bioproducts, nor steer the industry too much towards biofuels, as bioproducts will most likely be necessary for the industries profitability. General opportunities, needs and suggestions regarding the regulatory framework and governmental support to Nordic biorefineries are reported in section “Governmental Framework and Support”.

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Sammenfatning

I 2014 startede Nordisk Ministerråd et nyt Bioøkonomi projekt: "Test centers for green energy solutions – Biorefineries and business needs". Opgaven i dette projekt var at styrke også bioøkonomidelen af den grønne vækst. Metodetilgangen var at inddrage alle de nordiske lande i at få beskrevet status for bioøkonomi-relevante aktiviteter og identificere potentiale og muligheder, barrierer, og behov inden for både den private og den offentlige sektor (universiteter og industri).

Projektgruppen bestod af kompetente bioøkonomi-forskere og ministerielle ressourcepersoner fra hvert af de nordiske lande plus repræsentanter fra NCM. Professor Lene Lange, DTU, Danmark, blev udpeget til at lede og koordinere projektet.

Indeværende afrapportering fra dette NCM Bioøkonomi projekt indeholder tre hovedafsnit:

1. Executive summary chapters (Introduktion, Baggrund, Fremtidsudsigter, Konklusioner, Tendenser og aktioner, samt Anbefalinger, suppleret med Højdepunkterne fra de nationale afrapporteringer for hvert af de nordiske lande).
2. Fuldstændig status på bioøkonomirelevante aktiviteter og tilgængelig infrastruktur for hvert af de nordiske lande, samt Grønland og Færøerne.
3. En konsulent rapport (udført at Matis, Island), dækkende forretnings behov og muligheder inden for bioøkonomien, opgradering af biologiske ressourcer fra landbrug, skovbrug, havbrug samt organiske sidestrømme fra industrien og husholdningsaffald.

Opgradering af biomasse fra restfraktioner fra landbrug, skovbrug og fiskeri udgør et meget stort potentiale til forbedret udnyttelse af de biologiske ressourcer. Globalt set bliver omkring halvdelen af al primær produktion ikke udnyttet, men går til spilde. Omdannelse af restprodukter og affaldsstrømme til produkter af højere værdi danner basis for den nye Bioøkonomi. Omdannelse af biomasse til bioenergi er velbeskrevet og allerede udviklet til opskalering og kommercialisering, men udvikling af biobaserede produkter også til mere højværdiprodukter, såsom sunde foder og fødevareingredienser, special-kemikalier og nye funktionelle materialer er stadig i sin vorden. Det er ikke kun plantefibre der skal udnyttes; også proteiner, lipider, lignin, etc. Samtidig er det vigtigt at de nye biobaserede produkter er konkurrencedygtige med eksisterende produkter på markedet, så kommercialiseringen af nye produkter kan foregå på lige vilkår.

Ud fra denne status for bioøkonomiens teknologi og værdikæder, er opgaven lige nu dobbelt: hurtigt at få etableret bioraffinaderier på basis af eksisterende teknologi for at skabe arbejdspladser, forbedret ressourceudnyttelse og mere kompetitiv forretning; og at få udviklet processer og produkter til mere højværdi produkter, således at vi vinder både bioraffinaderi-teknologiføreskab, teknologieksport, jobs og markedsandele – også i årene der kommer. Gennem målrettet styrkelse af det nordiske samarbejde kan vi løfte begge disse to opgaver mere innovativt og mere effektivt. Indeværende rapport fokuserer på at tilvejebringe bedre grundlag for, hvordan dette kan gøres, både bæredygtigt, smart og hurtigt.

Profilen af den nye nordiske bioøkonomi er unik. Den mest gængse vej til at udvikle nye biobaserede produkter fra biologiske restmaterialer og organisk affald har været først at fokusere på at udnytte hvede og majs afgrøderester til bioenergi (f.eks. bioethanol). I de nordiske lande har man imidlertid allerede fra starten af bioøkonomien fokuseret ikke kun på bioenergi og ikke kun på plantemateriale, men på at udnytte flere typer biomasse (feks træ, fiskerester og husholdningsaffald), og på at opgradere også til mere højværdi produkter. Tilgangen har været at forsøge at udnytte biomassens fulde potentiale feks ved at gå efter både fibre og proteiner, fra planter og fra dyr, for at opgradere egnede biomaterialer til foder og fødevareingredienser; kemikalier og materialer.

Det andet karakteristika for udviklingen af den nye, nordiske bioøkonomi er at offentlige forsknings-programmer i alle landene i de sidste mange år har haft dette fagfelt i fokus for deres funding aktiviteter. Der er således nu aktive nordiske forskningsprogrammer inden for både den gule, den grønne, den blå og den industrielle sektor.

Den tredje parameter der karakteriserer den Nordiske bioøkonomi profil er at der satses på den tredobbelte bundlinje, forbedret ressourceudnyttelse, der kan give både forbedret miljø og klimaprofil plus forbedret økonomi og ikke mindst jobskabelse.

Den fjerde trend er at en hel række af relevante nordiske organisationer har prioriteret at have aktiviteter inden for bioøkonomiområdet, bioraffineringsteknologi og bæredygtig biomasseproduktion (Nordisk Ministerråd (NCM), NordForsk, Nordisk Komité for Jordbrugs- og Fødevareforskning (NKJ), SamNordisk Skovforskning (SNS), Nordisk Energiforskning (NEF), Nordregio, Arbejdsgruppen for fiskerisamarbejdet under Nordisk Ministerråd (AG-Fisk) samt Miljø og Økonomigruppen (MEG) under Nordisk Ministerråd for Miljø).

Indeværende NCM rapport påpeger ud over disse store potentialer og muligheder også en række områder hvor der er både barrierer og forhindringer for hurtig udvikling af Bioøkonomien. Det bevirker at gevinsten af bioøkonomien til gavn for forbedret ressourceudnyttelse, miljø og jobskabelse endnu ikke er høstet.

Eksempler på sådanne barrierer er mange (I, II og III):

I. Tilgængelige testfaciliteter (bioraffinaderi relevante apparatur og infrastruktur i både pilot og demonstrationsskala) er meget få. Det betyder at de allerfleste teknologier og processer forsinkes i opskalering ved at der skal investeres til at etablere sådanne faciliteter; på ny næsten hver gang. Den manglende deling af opskalerings infrastrukturer suboptimerer den samlede investering; og minimerer muligheden for at dele erfaring og procesudvikling mellem de forskellige segmenter og typer proces, produkt og forretning.

II. Det nordiske samarbejde er trods en hel række fælles nordiske initiativer og projekter på området ikke indarbejdet så solidt, at det resulterer i, at der tilsvarende arbejdes på tværs af de nordiske lande også i nationalt baserede projekter og forretningsinitiativer. Universiteter arbejder primært sammen med industri R&D fra deres eget land. Og industrien finder oftest universitets-ekspertise fra universiteter i det samme land.

III. Rammebetingelserne for udvikling af porteføljen af biobaserede produkter fra rest og affaldsstrømme er ikke blevet udviklet tilstrækkeligt endnu. Det gælder f. eks inden for det regulatoriske område, inden for incitamenter til markedsskabelse (f. eks. iblandingskrav mht. biobrændstof; eller politisk målsætning om stigende krav til procent genanvendelse og opgradering af biologiske ressourcer). Denne forsinkede udvikling forstærkes af at de politiske målsætninger inden for bioøkonomien har været meget mere beskedne end det potentiale området indeholder.

Anbefalingerne, der er formuleret på basis af rapportens sammenstilling, analyse og konklusion, adresserer netop disse begrænsninger og barrierer. Samtidig med at anbefalingerne peger på, hvordan øget nordisk samarbejde inden for netop Bioøkonomien kan give værdi til alle landene, ift både øget ressource udnyttelse, klima- og miljøforbedringer, jobskabelse og øget konkurrenceevne.

Denne rapport er en del af de nordiske statsministres grøn vækst *initiativ: "The Nordic Region – leading in green growth" – læs mere i webmagasinet "Green Growth the Nordic Way" på www.nordicway.org eller på www.norden.org/greengrowth*

Nordic Council of Ministers

Ved Stranden 18
DK-1061 Copenhagen K
www.norden.org

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Development of the Nordic Bioeconomy

In 2014 NCM initiated a new project: "Test centers for green energy solutions – Biorefineries and Business needs" to strengthen Nordic bioeconomy by identifying potentials, obstacles, needs and opportunities. The Nordic bioeconomy has a unique profile: Upgrade of many types of residues also to higher value products; good collaboration between private and public sector; R&D efforts in all Nordic countries. However, shortcomings were also identified: few activities across Nordic countries beyond designated Nordic programs; too few upscaling facilities; need for improved framework conditions (within regulatory and market stimulus) for biobased products.

This report is part of the Nordic Prime Ministers' green growth initiative: "The Nordic Region – leading in green growth" – read more in the web magazine "Green Growth the Nordic Way" at www.nordicway.org or at www.norden.org/greengrowth

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